Isolation from Ground Vibrations with Geofoam Barriers: Centrifuge Modelling

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ABSTRACT
Ground vibrations due to human activity can be reduced with the installation of vertical barriers within the soil. The efficiency of the isolation system depends on various parameters such as depth, width, distance from the source, wave length, etc. A centrifuge parametric study is conducted to examine the influence of the different parameters in some reduced scale models made of Expanded polystyrene (EPS) isolation barriers within Fontainebleau sand in order to determine geofoam isolation efficiency.

1 INTRODUCTION
The vibrations due to traffic, piling, blasting, industrial activities, construction and natural events like earthquakes can potentially damage buildings, disturb people and affect sensitive equipment and technical processes. The installation of an isolation barrier in the soil can reduce ground vibrations significantly by preventing the transmission of vibratory waves to the buildings in a determined zone behind the barrier.

The geometry, the position and the composition of the barrier affect the isolation performances. Although EPS barriers are effective in decreasing the transmission of traffic vibrations, their geometric characteristics providing the best reduction are not yet established, and few studies have been devoted to the efficiency of barriers made of expanded polystyrene (EPS).

A major difficulty facing the physical modelling of wave propagation is the adequate replication of the in situ stress field. Centrifuge modelling in this case is an useful tool. This paper presents a centrifuge parametric study conducted to examine the influence of the different parameters in reduced scale models made of Expanded polystyrene (EPS) isolation barriers installed within Fontainebleau sand with the objective of determining geofoam isolation efficiency.

In order to address this problem, a piezoelectric device is used to generate ground vibrations in centrifuge models at frequencies corresponding to actual traffic vibrations. Different parameters (barrier width, barrier depth, source-barrier distance and input frequency) are assessed in order to determine their influence on the efficiency of the geofoam barrier isolation system, and the amplitude of the vibrations with and without a barrier is compared.
2 WAVE’S INDUCED BY TRAINS

Cars, heavy vehicles and trains produce ground vibrations, which may transmit to the structural elements close to heavy traffic routes under the form of highly perceptible vibrations (Barkan 1962).

The vibration level depends on road/railway performances (roughness, structural condition) and on traffic characteristics (speed and vehicle weight). Traffic vibration frequencies recorded by Barneich (1985) in different spots with different road/railways and traffic conditions are presented in Table 1. Figure 1 displays the vibration tolerance thresholds recommended by Standard DIN 4150 (1999), upon which the values of the train vibration reported by Paolucci et al. (2003) are superimposed. Here train traffic generates vibrations that frequently exceed the limit considered as “troublesome to persons” but which may occasionally reach the “severe to persons” threshold.

Table 1. Vibration frequencies and vehicle characteristics (Barneich, 1985).

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Car</th>
<th>Bus</th>
<th>Truck</th>
<th>Train</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency (Hz)</td>
<td>3 to 30</td>
<td>9 to 27</td>
<td>10 to 35</td>
<td>10 to 40</td>
</tr>
</tbody>
</table>

The energy arising from the traffic is transmitted to the ground through body and surface waves (Woods, 1968). In a homogeneous half space medium, body waves propagate according to a spherical wave front in all directions, whereas surface waves propagate exclusively along the surface separating the two media without spreading through the inside of the earth. Consequently, the geometrical attenuation is greater for body waves than for surface waves.

Miller and Pursey (1955) have calculated the distribution of the energy generated by a vertically oscillating disk for the case of an elastic half space with a Poisson’s ratio equal to 0.25. It appears that 67 percent of the total energy passing through the body of the transmitting medium is due to Rayleigh waves, 26 percent to shear waves, and 7 percent to compression waves.
3 ISOLATION BARRIERS

According to Woods (1968), wave barriers can be divided into two groups, namely, active and passive isolation systems. Barriers placed around the vibratory source are active isolation systems whereas barriers located farther from the source and close to a site where the vibratory amplitude must be reduced are defined as passive isolation systems.

Dimensions and materials properties are the most important parameters in the efficiency of isolation barriers. Experimental and numerical methods have been used to determine the influence of the geometrical parameters for both active and passive isolation systems with open and in-filled barriers. Length \(\ell\), width \(w\), and depth \(d\) of the barrier as well as the distance \(r\) from the source are the main geometrical criteria to be considered for the design of isolation systems (Fig. 2).

The amplitude reduction ratio, \(A_{RR}\) for a selection of points indicates the isolation system efficiency (Woods, 1968). \(A_{RR}\) is the ratio of the amplitude with a barrier \(A_I\) (measured in a location behind the barrier) to the amplitude \(A_0\) without isolation system (measured in a dual location at the same distance from the source), expressed in terms of ground vertical displacement or spectral densities (Woods 1968, May and Bolt 1982). Trench barrier efficiency is satisfactory when \(A_{RR}\) is lower or equal to 0.25 (Woods 1968, Richart et al. 1970).

\[
A_{RR} = \frac{A_I}{A_0}
\]  

(1)

4 MODELING ISOLATION BARRIERS IN CENTRIFUGE

The present paper addresses the problem of isolation barriers using centrifuged small scale models for a parametric experimental study. The first stage in centrifuge testing consists in reducing the geometry of the problem to a 2D problem (Murillo et al. 2009), in which the barrier length is not considered (Fig. 2).
The soil used for this study is a NE34 Fontainebleau well-graded silica sand. This sand has been used in soil mechanics laboratories and for centrifuge modeling for more than twenty years, as the variability of its properties is low and the resources very large.

The studied barriers are made of EPS. This is a synthetic closed cell foam material made of fine to medium spherical particles of solid Polystyrene with a naturally occurring petroleum hydrocarbon mixed in as a blowing agent (Horvath, 2001). The generic term is geofoam (Horvath, 1997). The density of geofoam is only 1% to 2% that of the soil. Nevertheless, it has a remarkably high strength-to-density ratio and can withstand long-term compressive stresses up to 100 kPa (Horvath, 2003). Two geofoam densities are used 14 kg/m$^3$ and 16 kg/m$^3$ for the 20 mm and 40 mm wide barriers, respectively.

4.1 Piezoelectric actuator and instrumentation

The vibratory source is a piezoelectric actuator (PEA). The PEA is a PPA40M actuator from Cedrat Technologies. This actuator uses an external deformable frame to pre-stress ceramics. The characteristics of the PEA PPA40M are described in Table 2.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Displacement (µm)</td>
<td>40</td>
</tr>
<tr>
<td>Blocked force (N)</td>
<td>800</td>
</tr>
<tr>
<td>Stiffness (N/µm)</td>
<td>20</td>
</tr>
<tr>
<td>Resonance freq., free-free (kHz)</td>
<td>25</td>
</tr>
<tr>
<td>Response time, free-free (ms)</td>
<td>0.02</td>
</tr>
<tr>
<td>Resonance freq., blocked-free (kHz)</td>
<td>12.5</td>
</tr>
<tr>
<td>Response time, blocked-free (ms)</td>
<td>0.04</td>
</tr>
<tr>
<td>Voltage range (V)</td>
<td>-20..150</td>
</tr>
<tr>
<td>Capacitance (µF)</td>
<td>2.7</td>
</tr>
<tr>
<td>Resolution (nm)</td>
<td>0.4</td>
</tr>
<tr>
<td>Thermo-mech. resp. (µm/°K)</td>
<td>0.04</td>
</tr>
<tr>
<td>Height (mm)</td>
<td>48</td>
</tr>
<tr>
<td>Base depth, width (mm)</td>
<td>10.9</td>
</tr>
<tr>
<td>Mass (g)</td>
<td>25</td>
</tr>
</tbody>
</table>

A specific power electronic configuration is necessary to guarantee the quality of the signal of the PEA at high frequencies. Therefore, a Cedrat Technologies LC75C converter and an LA75C amplifier are selected. A Schlumberger 4450 signal generator is used to control the shape of the input signal and the frequency. The PEA is not placed directly on the soil surface but supported by a 30-mm diameter and 5-mm thick aluminium circular plate. The top of the PEA is fixed to a beam to maintain steady contact with soil and the transmission of vertical vibratory motions towards the model. To control the PEA behaviour, an accelerometer is placed on the circular plate and a load cell is fixed on the vertical axis of the PEA (Tab. 2).

To measure the vibration, six mini-piezoelectric accelerometers, ICP ® 325*10 models, are used. These sensors are used to measure the acceleration in three different points (40, 80 and 120 mm away from the barrier) (Figs. 4 and 5). The accelerometers are coupled to an integrated data acquisition system CAREMBA (Derkx et al., 2006) which is placed in the centrifuge swinging basket. The prescribed sampling rate is 50 kHz. A sheet of plastic is laid between the source and the soil to have a homogenous contact, avoiding “cratering” phenomenon under the source. This geometry has been used for all the tests, allowing comparison of the results.
To assess the effects of the different parameters of a barrier on the reduction of vibrations, all the tests must be conducted with the same initial conditions and the repeatability of the vibration system. The vibratory system behaviour is controlled using an accelerometer and a load cell placed close to the actuator for each frequency (Fig. 3). Then it is possible to obtain the same vibratory force and displacement input signal, in order to reproduce similar stress-strain response of the soil.
Figure 5 presents the displacement of the circular plate for different tests and frequencies within the range 100-2000 Hz. Most of the tests show that the plate shifts between 0.5 µm and 2 µm. The experiments carried out are considered as displacement-controlled tests for the applied frequencies.

The force measured by the load cell located at the top of the PEA (Fig. 6) increases at the highest frequencies due to the inertial response. These results confirm the high-quality performances of the vibration system as a displacement controlled device in terms of repeatability.

![Figure 6. Vibration system response.](image)

5 EXPERIMENTAL RESULTS

Figure 7 shows the typical results of time history for accelerometers A, B and C located on both the barrier and the free sides at the same distance from the source. The results show that the attenuation becomes significant as the length increases. These results correspond to an input frequency of 1800 Hz. Furthermore, a reduction in the peak acceleration is observed on the barrier side (Murillo et al., 2009).

5.1 Influence of the width of the barrier

Figure 8 summarizes the effects of barrier width on \( A_{RR} \) as a function of the dimensionless width \( W \) (width reported to wavelength). The wavelength is evaluated using the SASW method in centrifuge as described by Murillo et al. (2008). For \( W \) higher than 0.25 and for \( r = 50 \) mm, the amplitude reduction ratio is approximately 0.2 for all depths. On the other hand, for thinner barriers (\( W < 0.25 \)), the amplification of the acceleration might occur mainly with shallow barriers. These results agree with those found by Zelikson (1986), indeed the advice is to design barriers with a width equal to a quarter of the wavelength for a highly efficient isolation system.
Figure 7. Acceleration recorded at points A, B, and C on the free side, and A_B, B_B, and C_B on the barrier side. The input frequency is 1800Hz. (w=20 mm, d=340 mm, r=200 mm).

The results confirm that the influence of the depth is negligible for wider barriers. However, for shallow barriers the influence of the width becomes noticeable. This observation is consistent with the results obtained by Ahmad & Al-Hussaini (1991), Al-Hussaini & Ahmad (1996), and Itoh et al. (2005).
6 EXTRAPOLATION OF A REAL CASE WITH VIBRATIONS DUE TO TRAFFIC

In order to assess the efficiency of a geofoam barrier to reduce real traffic vibrations, \( A_{RR} \) results, obtained previously, are applied to the displacement generated by an actual train reported by Paolucci et al. (2003) (Fig. 1). A 12-m deep (240 mm at scale 1/50) and 1.0-m wide barrier (20 mm at scale 1/50) is examined. The vibratory source is supposed to be installed at a distance of 5 m from the barrier (100 mm at scale 1/50).

Figure 8. Influence of width for barriers placed at different distances from the source and different depths.

Figure 9. Amplification reduction ratio applied to a real case of train with vibrations.
Figure 9 shows a significant reduction in the displacement due to the barrier. These results prove that geofoam barriers could be a good solution to reduce traffic vibrations, especially high frequency vibrations. The amplitude vibrations registered using a geofoam barrier are located under the threshold considered as “barely noticeable to person” considering the limits proposed by DIN 4150 standard (1999).

7 CONCLUSIONS

Centrifuge modelling is used to simulate the vibrations generated by traffic to surrounding structures and to determine the efficiency of the isolation system using geofoam barriers.

In order to address this problem, a piezoelectric device is used to generate ground vibrations in centrifuge models at frequencies corresponding to actual traffic vibrations.

Different parameters: barrier width, barrier depth, source-barrier distance and input frequency are assessed in order to determine their influence on the efficiency of the geofoam barrier isolation system.

The amplitude of the vibrations with and without a barrier is compared. The vibration reduction is quantified using the $A_{RR}$ ratio and the results obtained show amplitude reductions ratio $A_{RR}$ ranging from 0.2 to 1.8.

The results show that the efficiency of the isolation system is dependent on the barrier depth. The influence of the barrier width becomes noticeable especially in shallow barriers and lower frequencies in contrast with deeper barriers and higher frequencies, for which the influence is negligible. Acceleration amplifications behind shallow barriers can be observed when the width-to-wavelength ratio $W$ is less than 0.2.

This parametric study has been conducted in order to provide some suggestions that can be use in the design of isolation system using barriers.

The efficiency of an active isolation using a geofoam barrier is satisfactory for $W>0.25$. This advice is valid for the soil mentioned in this study, for other parameters it is recommended practicing others tests.

References


