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Wave barrier of lime–cement columns against train-induced ground-borne vibrations

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ABSTRACT

This paper presents a comparison between measured train-induced ground vibrations in the free-field before and after countermeasures had been taken at Kåhög near Gothenburg in Sweden. A wave barrier of lime–cement columns was constructed parallel to the railway in order to reduce the ground-borne vibrations inside nearby buildings. On top of the barrier an embankment was built to reduce air-borne vibrations. Due to the wave barrier design, part of the energy content of the waves was expected to be reflected by the screen and transmitted energy was expected to be partly scattered. Contribution from the noise-embankment was not thought likely but could not be ruled out due to its fairly large mass and its close proximity to the railway. The effect of the mitigating measures resulted in a 67% reduction of the maximum particle velocity at 30 m and 41% at 60 m from the railway. A simple two-dimensional finite element model has been used to study the relative importance of the wave barrier and the noise-embankment as contributors to the mitigation recorded of the ground vibrations in the field. It is concluded with respect to ground vibrations that both the barrier and the embankment had a mitigating effect but that the contribution from the barrier dominated. Furthermore, it is seen from the field results as well as the simulation that the effect of the mitigating action is reduced with increasing distance from the railway.

1. Introduction

Ground vibrations caused by train traffic are of growing concern as faster and heavier trains operate within densely populated areas. Such problems are inevitable with increasing demands for mass transit with regards to travel time and frequency of services by the public and the aspirations from industry to increase freight capacity. Excessive ground vibrations increase the maintenance cost of track and may cause cosmetic damage to buildings nearby. However, the level of the vibrations is significantly higher than the level at which they become annoying to people or damaging to sensitive equipment. Annoying vibrations inside buildings have been reported as far away as 200 m and more on soft soils [1]. When designing new railway lines, therefore, a main concern of transport planners is the environment of people living and working in the area as well as delicate apparatus.

The more frequent use of railway lines increases the number of incidents when operations cause disturbance to residents or interrupt the use of sensitive equipment in the vicinity of the lines. One cause of stronger ground motion is greater train load, i.e. the quasi-static wheel pressure on the rail, that rises the amplitude of the induced vibrations in the ground and inside buildings [2]. Another significant effect that influences the response of the ground is the speed of the train, especially when approaching the critical wave velocity [3,4]. Factors such as rail joints and the roughness both of the wheels and on the rails are also important.

The site conditions significantly affect the ground response. The properties and geometry of the embankment as well as the soil under and beside the railway embankment are important factors that influence train-induced ground vibrations and can reduce or increase the vibrations [5].

One method to reduce ground motion caused by train traffic would be to impose speed reduction or limit the maximum allowed weight per train wagon. However, this is usually not in the best interest of the public and might not always be the most efficient solution. Reducing the speed and weight of the train is most suitable if the critical wave velocity in the soil is being approached and or if it is the near-field that is of most concern. A variety of different countermeasures has therefore been developed and implemented in order to reduce train-induced ground vibrations, including soil stabilization, continuous slabs

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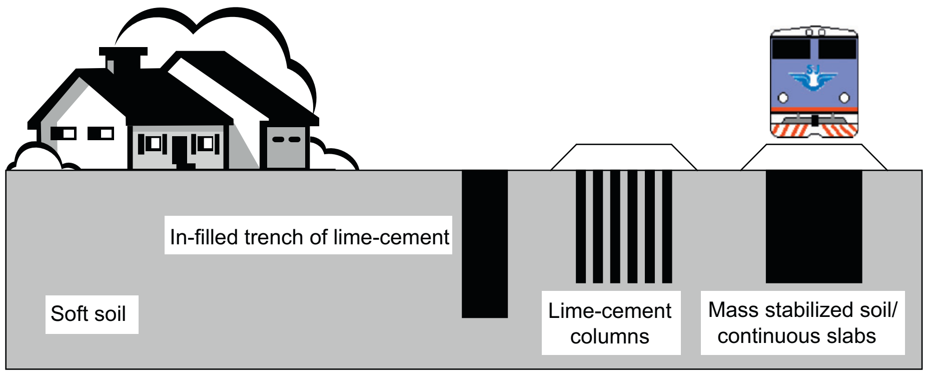

Fig. 1. Schematic showing a selection of countermeasures.

under the railway embankment and wave barriers in the ground, open [6–8] or filled [9,10], respectively as well as combinations [11] (see Fig. 1). Not shown in the figure are countermeasures that fall under maintaining of the track; rail grinding, pads for rail and slippers as well as a more intrusive action like adjusting the material of the railway embankment by adding or removing it in order either to gain a more uniform or increasing the stiffness.

This paper reports on ground vibration measurements from a site where a wave barrier constructed of lime–cement columns and a noise-embankment were built on top of each other and parallel to the railway. The focus is on presenting the field measurements in the vicinity of the track and discussing the importance of the respective countermeasures. A simple two-dimensional (2D) modelling in ABAQUS is carried out and presented to support the discussion and conclusion from the field survey.

A barrier is constructed primarily to reflect, damp and scatter the incoming wave, thereby reducing the intensity of the vibrations and the size of the affected area around the railway line. The degree of reduction is dependent on the relation between the dimension of the barrier and the lengths of the present waves together with the impedance contrast between barrier and surrounding soils. This has been numerically and experimentally studied by several researchers [8–13].

The purpose of the lime-cement barrier is to shield the area behind it from excessive vibrations caused by the railway. This is accomplished by reflecting incoming waves against the stabilized soil with greater impedance contrast as well as damping and scattering of the proportion of the waves that are transmitted through it. If the barrier is successful, the amount of energy remaining in the waves arriving at the objects of concern is reduced to such an extent that the ground motion is acceptable for the people living in the area.

The process of constructing a column of lime and cement is schematically presented in Fig. 4. A nozzle with mixing tool is lowered to the required depth. As the nozzle is raised to the surface, the desired blend of lime and cement is added under pressure and mixed with the soil. Water, present in the clay, reacts with the binding agent (in this case lime and cement) and the process in general, results after some time in a stabilized soil with increased strength and thereby increased impedance. The density of the soil is not significantly altered. The Nordic dry deep-mixing technique used in Kåhög and here briefly presented is in more detailed described in Refs. [14–17].

2. Site conditions

The wave barrier was constructed in Kåhög, 10 km east of Gothenburg on one side of the main railway line toward Stockholm. The barrier was made with lime–cement columns side-by-side in four rows parallel to the track, 0.80 m diameter and 0.65 m c/c. The four rows of columns were 3.9 m apart. The distance from the railway to the closest row was about 6 m. Similar lines of columns were constructed perpendicular to the railway embankment with 3.25 m spacing to achieve a grid formation (see Fig. 2). The outside dimension of the barrier was about 280 m along the railway, 12 m wide and 12 m deep. In total, 3230 columns were made with a combined length of nearly 39,000 m. On top of the wave barrier, a wall with a triangular cross-section was constructed to reduce the air-borne noise generated by the railway traffic. The height of the wall was 4 m and the base 15 m (Figs. 3 and 4).

The length of the barrier was made to cover the whole length of buildings of interest, flanks were extended. It was acknowledged that a barrier with greater depth would probably have been more efficient. However, it was judged that the lime–cement columns created at depth below 12 m would not have increased the impedance enough to motivate the extra cost. The depth of 12 m was believed to be adequate to reduce the waves with wavelengths less than that dimension. It would decrease the magnitude of the vibrations inside the buildings to an acceptable level.

The soil at the site consists of about 1 m dry crust of organic clay overlaying approximately 15 m of silty clay with some thin layers of silt and sand. The undrained shear strength of the silt is about 15 kPa in the top layer and increases up to about 30 kPa at 14 m depth. The density of the soil varies between 1.6 and 1.9 metric ton/m^3 at different depths. The water content varies through the depth between 30% and 65% and the groundwater is about 2–3 m below the surface. Figs. 5 and 6 present data from two bore holes at approximately 10 and 50 m on the northern side from the centre of the northern railway track.

3. Measurements and instrumentation

Measurements were carried out on two occasions at the site (in 2002 and 2004). Results from measurements presented here were taken on the upper surface of the railway embankment, at two positions at distances of 30 and 60 m from the centre of the northern track on the north side. The section was in line with the eastern border of property 11:12 (Fig. 2). In additions to gauges for measuring the ground motion, strain gauges were installed on the rail.

Results from observation positions at 30 and 60 m were used to show how the maximum peak particle velocity in the vicinity of the track is affected by the construction of the countermeasure. Gauges on the railway embankment were used to determine the speed of the trains. The strain gauges on the rail measured the