Reducing train induced ground-borne vibrations with deep stabilization – technical and economical feasibility

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Summary

Due to urbanization and ecological aspects there has been a growing need to plan new residential areas with easy access to the public transportation. In many areas in Finland, new housing is located close to railway or metro lines. Depending on soil conditions, there is a risk of having acoustical challenges related to vibration or ground-borne noise. A research project funded by the Finnish Transport Agency was conducted in which a deep stabilisation was used to mitigate ground-borne vibrations and to protect a new housing area located near the main national railway track. Research project and the acoustical engineering related to the vibration mitigation structure was carried out by the department of acoustical engineering of AINS Group. Research included field measurements before and after the construction of the mitigation structure as well as cost analyses with respect to the permitted building area. According to the measurement results in the vertical direction, attenuation was estimated to be about 50 % at the distance of 10 meters from the structure. At the distance of 45 meters the attenuation was about 40 %. In the horizontal direction, attenuations of 80 % was measured at both distances. Housing protected by the stabilisation structure consisted of about 13 250 square meters and the total cost including constructor work was estimated to be 83 000 € (0 % VAT). From these figures one can notice that in this case, the cost of the mitigation structure per housing area is only about 6,30 €/m^2 meaning that it is a very cost-efficient way to reduce train induced vibrations.

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1. Introduction

In recent years, planning near railway lines has been common in Finland, especially in the growth centres. Areas close to railways are becoming more attractive due to growing importance of public transit and the lack of available land in city centres. In order to turn these areas into housing, cost-efficient noise and vibration mitigation solutions are required. The costs of these solutions will end up rising the property prices for the end user. For the railway operators and railway owners it is important to have mitigation solutions other than lowering of train speeds. The cost-efficiency of mitigation solutions for airborne noise has been addressed in recent research projects [1] whereas the cost-efficiency of ground-borne vibration mitigation has been studied less.

Railway-induced ground-borne vibration and ground-borne noise can be mitigated at the source of vibration, on the transmission path or at the site [2]. During the planning of new railway tracks or buildings, the available mitigation solutions depend on the existing tracks or buildings. In the case of already existing railways and buildings the variety of available solutions is very small and mostly limited to transmission path solutions.

In this study, the focus is on a transmission path solution, namely a ground barrier or stabilisation structure that is used to mitigate vibration caused from an existing railway to a new housing area. Previous studies have focused on the technical aspects of similar solutions [3-4]. However, the feasibility of these technical solutions is also largely effected by the economic aspects. Therefore, in this study the final costs of the solution with respect to built floor area.

2. Research project

The subject area of this study is located in Southern Finland near the city centre of a mid-sized city and next to the Finnish main railway line. The planned buildings, a total floor area of 13 250 square meters, are presented in Figure 1. An assessment of ground-borne vibration and ground-borne noise was conducted as a part of the planning process. It was found that the Finnish recommendations for limit values of traffic-induced ground-borne vibration in housing [5] were to be exceeded. In order to make the construction of the area economically viable, the most cost-efficient solution for the mitigation of vibration needed to be found. The technically suitable solutions to the situation were assessed in terms of their technical and economic viability.

The solution of choice after the assessment was a lime and cement soil stabilisation structure close to the residential buildings (see Figure 1). The buildings closest to the tracks are located approximately 65 meters from the nearest track and the stabilisation structure was located around three meters from these buildings.

The test structures implemented earlier in Finland have mainly been located near the railway tracks and their mitigation efficiency has been found to decrease with growing distance to the structure [3]. Therefore, there was a need to study the mitigation efficiency of structures located close to residential buildings as well as their costs. The results were to be used in the assessment of usability of these solutions in future planning projects. This research was funded by the Finnish Transport Agency.

3. The vibration mitigation structure

The vibration mitigation structure was designed by the Acoustics Unit of the Ains Group while the stabilisation structure and the related construction work documents were provided by the Geotechnical Unit of the Ains Group.

The implementation principles of the stabilisation structure are depicted in Figures 2 and 3. For the lime and cement stabilisation, columns with a diameter of 600 mm were used in two rows. The two rows of columns are connected by intermediary columns every 2,5 meters. The structure extends through the soft soil down to the

Figure 1. Residential building four to eight-story high are planned in the studied area. The buildings consist of a total of 13 250 square meters of housing floor area and 1 731 square meters of common floor area as well as support spaces. The stabilisation structure is located on the west side of the buildings closest to the tracks and consists of a 100 meter long north-south part and 25-meter east-directed parts at either end.

hard deeper layers. The heights of the columns vary between 8 and 13 meters following soil variations. The shear strength target of the columns was set to 150 kPa in the design and in the construction documents.

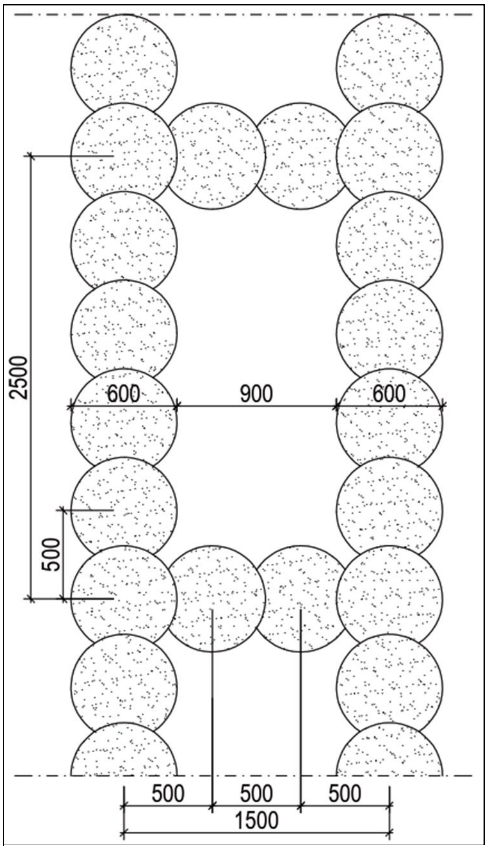

Figure 2. The columns were placed so that the stabilisation structure consists of two parallel barriers connected by perpendicular rows of columns. Mesures in millimeters.

4. Measurements and results

Before the call for bids, a cost calculation was conducted. The estimated total cost of the stabilisation structure was approximately 83 800 € (excl. VAT) including site management and construction work. The cost of the mitigation structure was approximately 6,30 € per one square meter of housing floor area (excl. VAT).

The final strengths of the columns were investigated. There was a total of 13 investigated columns and by the time of the tests they had been hardening for 21 to 29 days. According to the tests, the structure fulfilled the requirements set in the design.

Before the construction of the stabilisation structure, measurements of ground-borne vibration were conducted in the area in order to investigate the reference vibration levels of the initial setting. The measurements were conducted in fall 2016 on two measurement lines. The stabilisation structure was constructed afterwards in late 2016. In spring 2017, after the structure was let to harden and before the beginning of the building construction, ground-borne vibration measurements were conducted again on the same measurement lines.

The dampening ratios of vibration levels calculated from the measurements after and before the construction of the stabilisation structure are depicted in Figures 4 and 5 separately for different train types. The calculations were made according

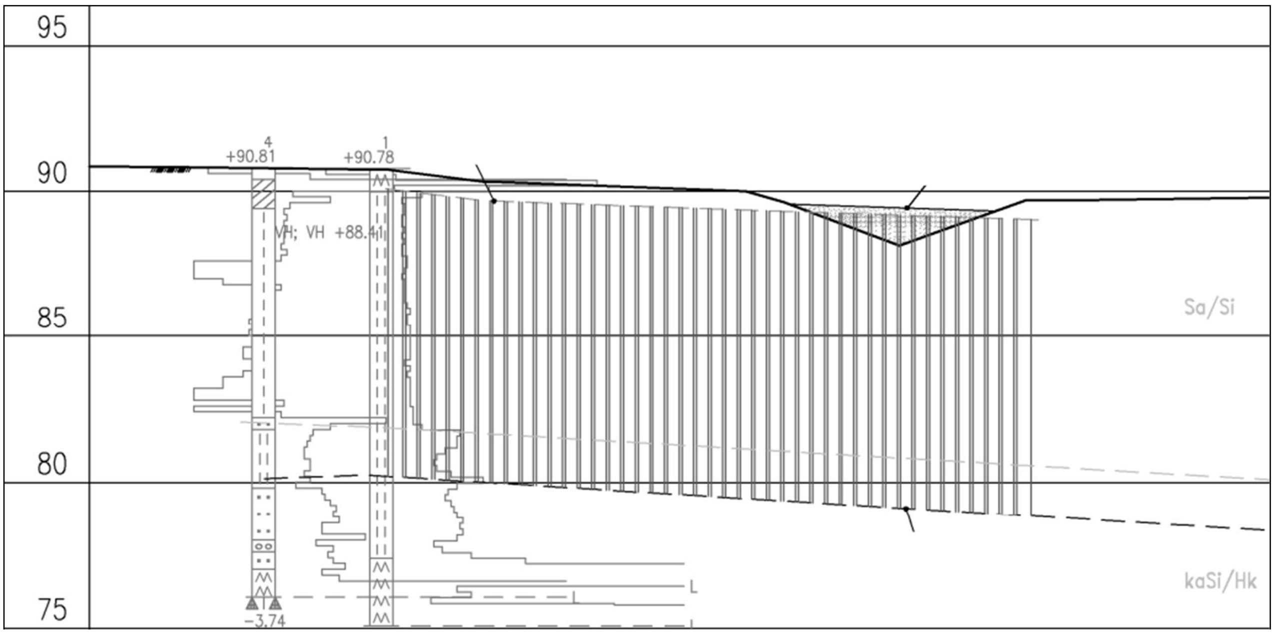

Figure 3. Part of the longitudinal section of the implemented stabilisation structure. The height of the columns depends on the soil.

to the guideline of the Technical Research Centre of Finland (VTT) [5] using the maximum RMS values of the frequency-weighted velocity signals. Based on the results, the horizontal vibration levels were attenuated approximately 80 % on average for all passenger train types at both distances 10 and 45 meters from the stabilisation structure. For vertical vibration levels, the corresponding attenuation was approximately 50 % at 10 meters and 40 % at 45 meters.

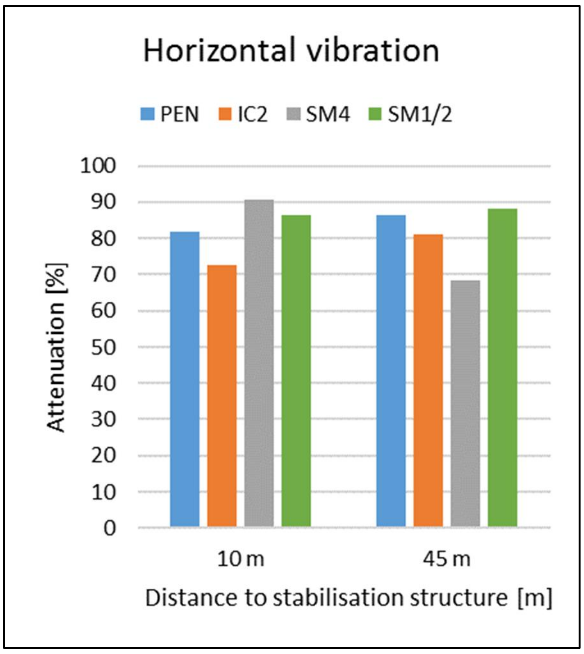

Figure 4. The attenuations of the horizontal vibration levels due to the stabilisation structure at 10 and 45 meter distances from the structure presented by train type.

5. Discussion

In earlier studies conducted by the VTT [3], the vibration attenuation properties of implemented in-ground sheet pile walls and stabilisation structures have been studied. The attenuations of horizontal and vertical vibration levels in various sites are depicted in Figure 6.

In these previous studies by the VTT, the conclusion has been for the vertical vibration to attenuate on average 40 to 50 % right behind the barriers and 20 to 30 % at a 60-meter distance. In the horizontal direction, the attenuation has varied largely between the sites: In some cases, the attenuation has been over 50 % whereas in others there has been no significant attenuation. On average the attenuation for horizontal vibration has been approximately 20 % [3]. The attenuations by

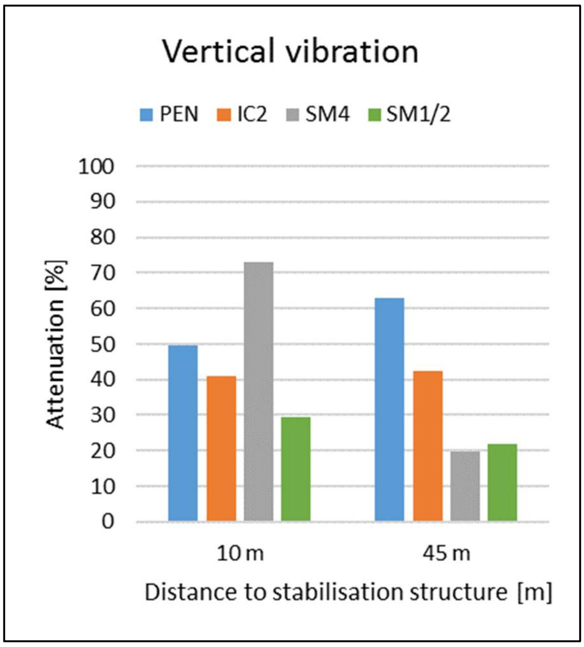

Figure 5. The attenuations of the vertical vibration levels due to the stabilisation at 10 and 45 meter distances from the structure presented by train type.

columns stabilisation structures have been somewhat better at two sites than the average attenuations of all sites.

In the earlier studies, the mitigation structures were constructed near the railway tracks at a distance of 7 to 10 meters. The barrier constructed in this study, was at about 60 meters from the track and close to the planned buildings. Based on the measurement results, an attenuation of approximately 50 % was found at a distance of 10 meters from the barrier and 40 % at a distance of 45 meters. The attenuation for horizontal vibration was approximately 80 % at both distances. There was, however, significant variation between the train types, especially for the vertical vibration. Overall, the vertical vibration attenuation was on the same scale with the earlier studies, while the horizontal attenuation was more efficient than in earlier studies.

6. Conclusions

The target strength of the stabilisation structure was achieved. The costs of the construction corresponded to the estimated costs and therefore the cost of the mitigation structure for the housing in the area was approximately 6,30 € per square meter of floor area. The stabilisation structure can be a cost-efficient solution for area-wide ground-borne vibration mitigation. However, the cost-

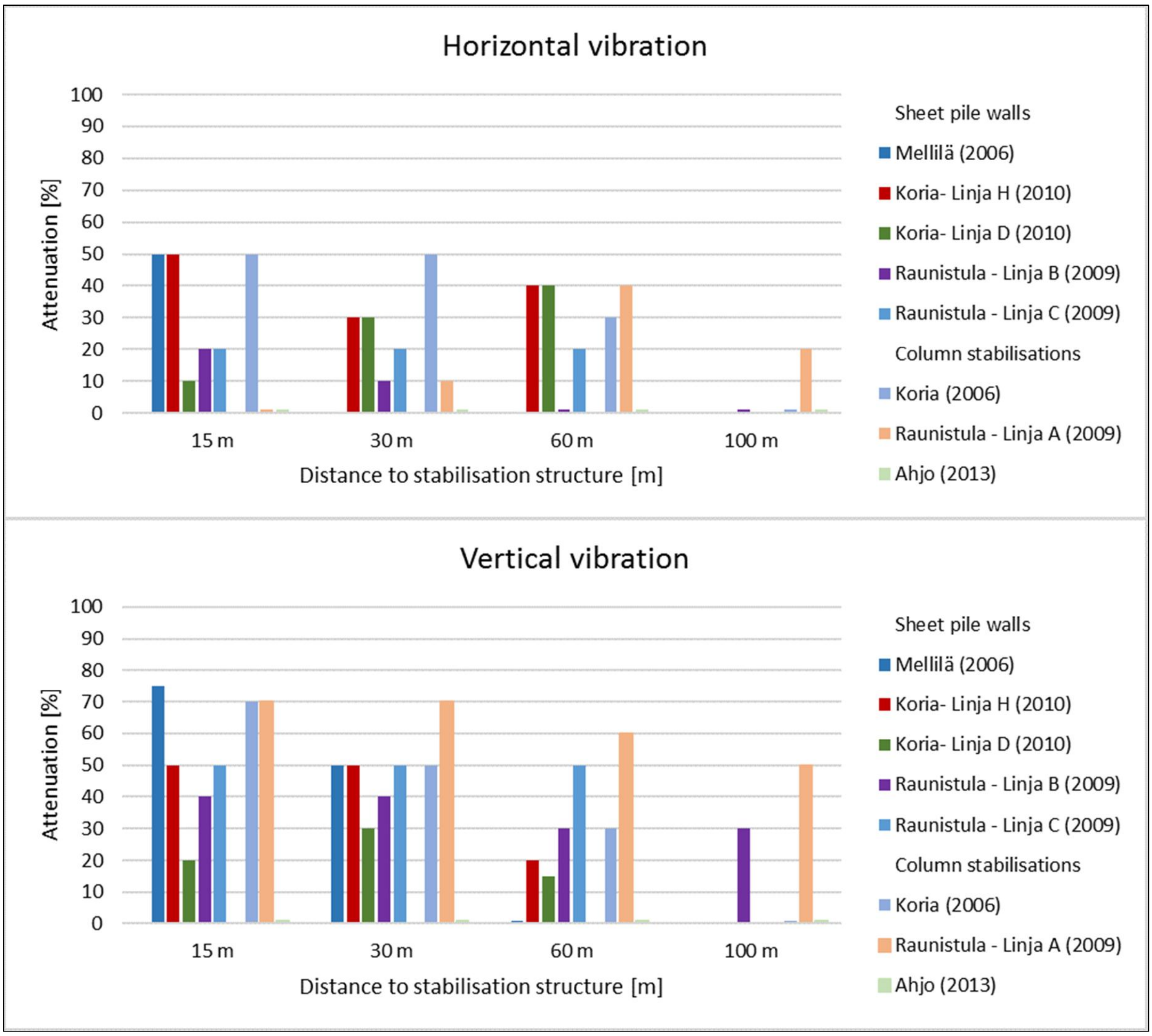

Figure 6. A conclusion of attenuation results of vibration barriers in previous studies at various distances from the track. The Ahjo site mitigation structure and soil properties were different from the others sites. Figure is based on reference [3].

efficiency of the solution is strongly influenced by the planned floor area and the depth of soft soil layers in the area.

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