Vibrations caused by train traffic and the effect of its mitigation on the quality of living

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ABSTRACT

Railway traffic induced vibrations in dwellings often cause irritation or disturb the inhabitants. Mitigation has been performed, and measurements prove their effectiveness. The effect of vibration countermeasures on the quality of living however has not been studied earlier. The objective of the study was to evaluate the effects of vibration mitigation compared to the increase of inhabitant satisfaction, would the halving of vibration levels lead to a doubling of satisfaction? The investigation was done by means of a literature study, vibration measurements and written surveys with the financial aid of the Finnish Rail Administration. The testing was carried out in Raunistula, a suburb of Turku, in Southwestern Finland. Passing along the side of the residential area, the Toijala-Turku railway line causes vibrations in the surrounding areas affecting the quality of residents’ life. To attenuate the vibration, two different structures were constructed, a sheetpile wall and a matrix of lime-cement columns. Typical to the Southwestern region of Finland, the soil in Raunistula consists of a thick layer of clay with low shear strength. This soil type allows large displacements in railway sub-structures, especially if ground supported. Additionally, the low natural frequency and damping coefficient of clay lead to minimal attenuation and widespread effects in the surrounding area. The level of vibrations and residents’ satisfaction was evaluated prior to construction. After the installation of the aforementioned barriers, a new round of measurements and surveys was performed in order to find out how the mitigation succeeded. Results were satisfactory, the greatest amount of mitigation was achieved nearest to the track and comments of a rise in the quality of living were achieved. The mitigation however was limited to a certain distance from the track. Farther away, partly due to other sources of vibrations and noise, the mitigating effect of the structures was negligible. The results of both the surveys and measurements show an improvement of 30 to 50 %, confirming the hypothesis that inhabitants' satisfaction increases as much as the intensity of vibration decreases.

Keywords: vibration, damping, test structure, railway, evaluation

1 INTRODUCTION

Vibrations from train traffic, their effects and damping have been studied, and a mitigation of 30 to 50 percent has been achieved with various barriers. Studies of the effects of the mitigation on the people affected, however, have not been done. General positive feedback will not tell how much change has actually happened. Only a systematic compilation of data will show how much the perceived level of vibration decreases and how the vibration mitigation is evaluated by the inhabitants.

The goal of this study was to evaluate the effectiveness of the constructed damping structure, and its effects on the living conditions and perceived level of vibrations.

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2 VIBRATION CHARACTERISTICS

Periodic vibrations of the soil caused by the trains’ load on the track and its substructure radiate away from the source. When the vibration reaches objects (buildings or people), it is transmitted causing a sensation that is usually regarded as disturbing.

Train induced vibrations’ dominant form is the Rayleigh-wave, which transmits almost 70% of the energy [1]. The frequency varies depending on e.g. the foundation and soil type. For a ground-supported track on a clayey soil, the dominant frequencies are usually low, around 10 Hz.

2.1 Human vibration

The human sensory system can pick up even very slight vibrations. The intensity of the sensation depends on the vibration magnitude and also on its direction and the position of the body. The natural frequency of the human body is 4 to 12 Hz [2] [3]. Sensing a vibration and its psychological effects are a complex process, but in 1957 S.S. Stevens showed that the intensity of the vibration and the sensation it causes have a linear correlation [3]. Sensing these vibrations often cause fear of structural damage or even failure, even at lower intensities than what is required for it to occur [3]. Other effects are: [4]
- decline in comfort;
- interruptions in concentration;
- interrupted sleep or rest;
- fear of loss in property value.

2.2 Noise and vibration

When dealing with the annoyance caused by vibrations, one cannot dismiss noise. Structural vibrations often cause sound, on their own, or by rattling objects. Especially at nighttime, when ambient sounds are at their minimum, traffic induced noise can be regarded as annoying [5].

Continuing of the path laid out by Stevens, the relation of sound and vibration intensity to their combined sensation has been formulated. The gravity of noise is lower than of vibration [6]. The correlation can still be approximated to be linear.

3 TEST STRUCTURE

The test site is located in Raunistula, a suburb of the city Turku. The single track railway that runs past a suburban housing area causes vibrations of a disrupting magnitude.

The soil conditions are typical to the southwestern coast of Finland; the topography of the area is quite flat. The soil under the round supported track and the houses is comprised of soft clay 20 to 25 meters deep with a shear strength of 14 to 37 kPa. A layer of silt and sand 5 to 10 meters deep lies between the clay and the bedrock.

Buildings in the area are mostly wood or brick-framed detached houses, built in the 1950's. The distances from the houses to the track range from 10 to 300 meters.

3.1 Mitigation barrier

Two different types of structures were incorporated into the barrier. The southern end of the structure was a sheet pile wall, and the northern part was a barrier of lime-cement columns. The total length of the barrier was 440 meters.

The sheet pile wall was 12 meters deep, and consisted of standard sheet piles with an elastic modulus of 118 MPa. The sheets were welded together with a horizontal steel beam to ensure performance as a single unit. The beam also eliminated the sinking of previously installed sheets as following sheets were forced into the ground.
The lime-cement columns making up the other end of the barrier were 16 meters deep, with a diameter of 800 mm. The columns were set up in a ladder like formation, Figure 1. The mixture of lime and cement was 1:1, added at 160 kg/m³.

4 MEASUREMENTS AND SURVEYS

The effectiveness of the barriers was determined by vibration measurements from the soil and surrounding buildings, before and after construction. The observation period was one week; measurements were taken from all three axes. In addition, data on passing trains (timetables, loads, speed) were acquired to assist analysis.

Soil vibrations were measured via a 500 mm long 20mm steel rod inserted into the ground. In houses, the sensors were mounted directly to the building frame or placed on the floor on top of a heavy base plate. A total of 46 points were measured prior to the construction phase with five measurement lines and scattered points, presented in Figure 2. After construction, measurements were carried out in 32 points. One measurement line, line D, was left out.

Like the vibration measurements, the residents view on the vibrations was surveyed before and after construction. The surveys were sent by mail. The questions covered the magnitude and the disturbance of the vibrations, the amount of noise created and the combined effect of noise and vibration. Additionally, the survey included questions on the type and condition of the building, and general information of the inhabitants. The survey consisted of 29 questions aimed to find out the amount of disturbance inflicted upon the residents by the train traffic. One of the questions asked for a numerical answer on a 0 to 10 scale, the rest were verbal.

The latter survey was nearly identical to the first one; the most significant differences was added questions on the change in the amount of discomfort and quality of living.

5 RESULTS

5.1 Vibration measurements

In measurements done prior to the construction phase, the train traffic induced vibrations were very strong. Vibration levels measured from the buildings were over the national guideline of 0.6 mm/s. Only in one building were the levels below the limit, but the house was over 160 meters from the track. The highest level of vibration was measured 14 meters away from the track, 2.34 mm/s. The frequency of the vibrations measured was 6.3 Hz, which was anticipated. Unfortunately it is also in the range of the resonant frequency of the areas buildings, 5 to 8 Hz [7]. Vibration levels dampened as they progressed away from the track.

Figure 3 describes the amount of vertical soil vibration in the area; values have been interpolated from measurements. The darkest areas by the track show strong vibrations. The
light band in between is the borderline of an acceptable level of vibration, 0.6mm/s.

Figure 3. Vertical vibration velocity contours, before mitigation efforts.

The second set of measurements showed a clear drop in vibration levels. Vibrations in only one building were over the guideline limit. Peak values of vibrations were again measured right by the track, topping at 2.41 mm/s, showing that the mitigating effect is not so strong at short distances from the track. Some sensors positioned over 100 meters from the track did not yield any results. The vibration in these points was so weak that it did not cross the threshold level of the sensors.

The average frequency of the vibrations had dropped to 5.5 Hz, mostly due to mitigation on the over 10 Hz region.

The best results were achieved on line A, where the barrier consisted of lime-cement columns. Least satisfactory results were found on line E, where the end of the sheet pile barrier in part lessened the mitigating effect.

Figure 4 describes the amount of soil vibration in the area, after the construction of the barriers. The trend is similar to the previous measurements results, but the level in intensity has lowered.

The vibration resultant gives a good general sense of how the barriers mitigate vibration. Results are displayed in Figure 5, values under 1.0 indicate the level to which the vibration has lessened.

Vertical vibrations were effectively mitigated. On average, the intensity nearly halved on all lines. Horizontal vibration components did not mitigate so well, especially near the track.

Figure 4. Vertical vibration velocity contours, after mitigation efforts.

Vertical vibrations were effectively mitigated. On average, the intensity nearly halved on all lines. Horizontal vibration components did not mitigate so well, especially near the track.

5.2 Surveys

The response rate to the survey was about 50%, which was considered to be satisfactory. The answers reported that the vibrations are very annoying and in most cases even evoked a fear of damage being done to the buildings. Vibrations also affected sleep and rest, as they were felt most strongly at nighttime and when lying down. On a 0 to 10 scale, the adversity of the vibrations was rated to an average of 8.2.
In the second survey, results showed that the level of vibrations had dropped significantly. The numerical average of the vibrations adversity was only 5.4 and some of the responses indicated that vibrations were no longer felt at all. Numerical ratings before and after the mitigation are presented in Figure 5. Dark columns are results before and light columns after mitigation.

![Figure 5. Numerical ratings of the amount of disturbance caused by the vibrations.](image)

As the annoyance of the vibrations had diminished, various inhabitants rated the annoyance of the noise induced by the traffic as more disturbing. The fear of structural damage was still quite strongly present.

The survey results did not correlate to the distance to the track. Variance on the answers grew between the surveys. Both can be explained by how each individual has a unique way of interpreting the vibrations, which is enhanced at lower levels of vibration.

One quarter of the respondents did not feel that the level of vibration had lessened. The rest, though, felt that it had lessened by a little or even a lot. An increase in the quality of living was reported in half of the responses. Overall, positive feedback was received in the open comments section.

A clear difference between the different mitigating structures could not be seen from the survey results.

6 CONCLUSION

The surveys indicated a clear drop in the disruptiveness of the vibrations, assessed by the inhabitants to be 30 to 60%. The vibration measurements gave similar results, with a mitigation of 25 to 50%. The mitigating effect was stronger with the lime-cement column barrier, but it can in part be the result of a difference in soil conditions as the vibration levels were slightly lower to begin with. The sheet pile wall was especially ineffective against horizontal vibration components. In the buildings, vibrations were mitigated by 30%, and in most houses the national vibration intensity limit was not exceeded after the construction of the barriers.

Similar mitigation studies have set the limit for a successful mitigation at 30 to 50%, which was in this case, met. Additionally, as the results from surveys and measurements yielded similar values for the mitigation effect showing that they correlate well together.

Fear of structural damage caused by vibrations persisted, remaining the key source of discomfort in the inhabitants. While sharing information on the vibration and its damage causing potential will not lower the amount of vibrations, it remains a cost-effective measure in increasing the inhabitants comfort and quality of life.

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REFERENCES


