



Vibration and low-frequency noise

Summary report

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Prepared by:	EDTA	Date: 2023.06.12	
Reviewed by:	OLWI	Date: 2023.06.12	
Approved by:	LXD	Date: 2023.06.12	
OL Accountable:		Date:	

Distribution

Odense Letbane P/S

Document Owner

*Odense Letbane P/S
Odeons Kvarter 18
5000 Odense C
Denmark
www.odenseletbane.dk*

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1. Introduction

During operation of the Odense light-rail complaints regarding train-induced vibrations and low-frequency noise have been received. Therefore, to quantify the level of vibrations and low-frequency noise inside the dwellings, measurements have been carried out. The obtained levels of vibrations and low-frequency noise have been evaluated against the guidelines specified in the Danish Environmental Protection Agency, no. 9/1997 "Low-Frequency Noise, Infrasound, and Vibrations in the Environment", referred to as "DEPA no 9/1997".

The locations for the measurements have been selected among the most exposed dwellings to train-induced vibrations. The most exposed dwellings are the ones closest to the track, and they have been selected in such a way that the most complete picture of vibrations and low-frequency noise is collected. This includes, from a vibration point of view, the 3 different track superstructures, the 2 fundamental building types and operational light-rail speeds gained from several passages. The tracks comprise 3 mitigation types in the superstructure, namely "10 dB mitigation mats", "20 dB mitigation mats", and the solution without any mitigation mat. The building types comprise single family homes and multi-story buildings. Furthermore, the measurements are conducted at the top floors, where possible, with the aim of obtaining the highest vibration levels from the light-rail operation.

In each of the selected dwellings vibrations and low-frequency noise have been measured simultaneously. The measurements have been conducted during normal operation of the light-rail.

2. Measurements

Seven locations along the alignment have been selected for the measurements. The measurement locations can be seen in Figure 1 and in Table 1. The table shows the address for each location as well as distance to the closest track, mitigation type, and building type. These are the conditions having the most impact on vibrations and low-frequency noise levels inside the dwellings.

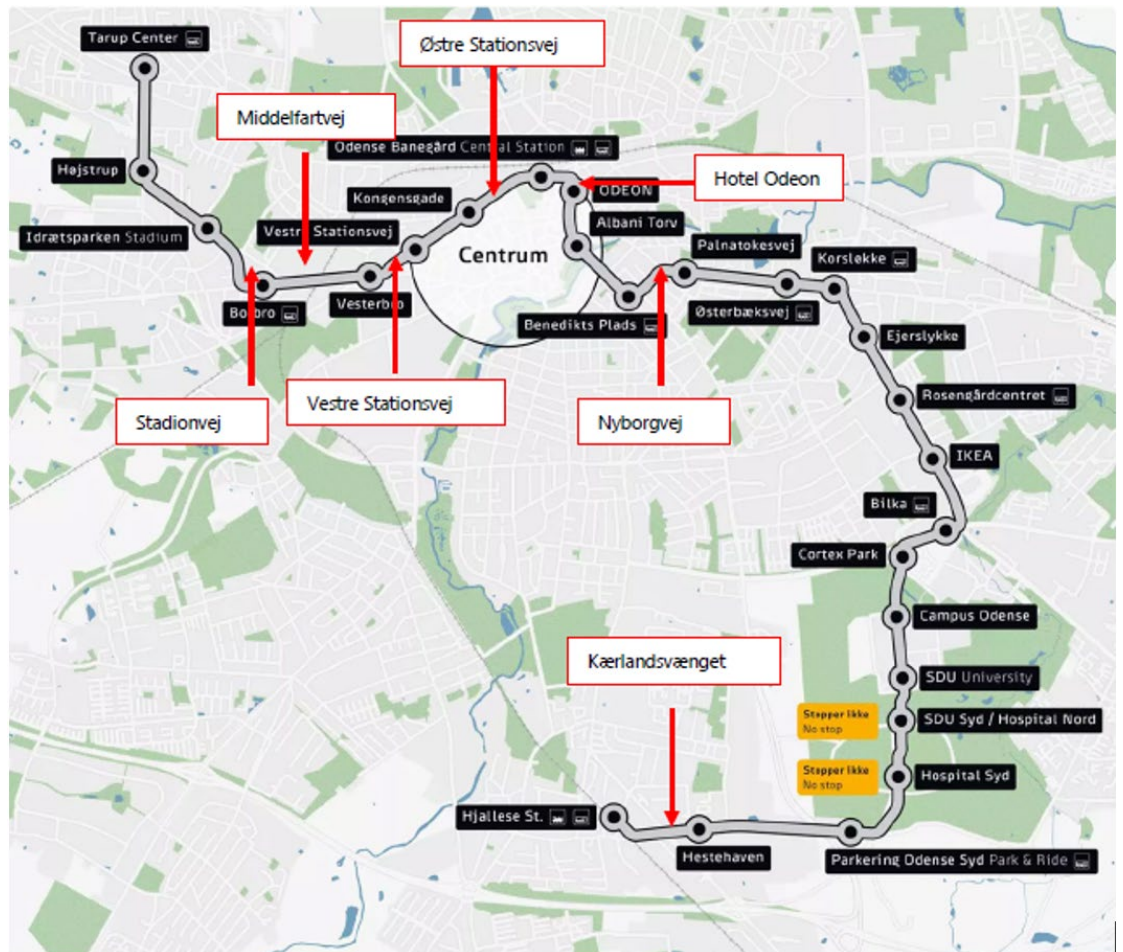


Figure 1: Indication of the measuring locations along the light-rail alignment shown with a thick grey line.

Table 1: Seven addresses with corresponding track mitigation type, distance to centre of closest track, type of accommodation, and train speed.

Address	Mitigation in track	Distance to track	Dwelling type
Stadionvej	10 dB	8 m	3 story multi-story
Middelfartvej	No mat	8 m	4 story multi-story
Vestre Stationsvej	10 dB	5,5 m	2 story single-family home
Kærlandsvænget	No mat	14 m	2 story single-family home
Østre Stationsvej	10 dB	4 m	4 story multi-story
Nyborgvej	10 dB	8 m	2 story single-family home
Hotel Odeon	10 dB	5 m	Hotel

The measurement campaign has been carried out during the period from May 8, 2023 to May 17, 2023 and at each location at least 15 train passages have been measured. The measurement campaign has been conducted according to "DEPA no 9/1997" as specified in the following.

2.1 Vibration measurements

The vibration measurements have been conducted by a certified vibration specialist from 103 Rådgivende Ingeniører ApS, accredited by DANAK under reg. no. 620. Measurements are carried out in accordance with the company's procedure P7: "Måling af vibrationer".

Three accelerometers of type 3192A from Dytran, which measure vibrations in each of the three directions, namely vertical, longitudinal (parallel with the facade) and transversal (perpendicular to the facade), have been used for each measuring point. The measurement setup comprised two measuring points installed in the

same room of the chosen dwellings. The room assessed to be most exposed to vibrations has been selected for the measurements.

The measurements have been done continuously, recording KB-weighted vibration levels every $\frac{1}{2}$ second in all three directions with time weighting "slow". The sensors are attached to a 9 kg heavy tripod stand and installed directly on the floor. The measurements were done supervised, and with a camera monitoring the light-rail for the purpose of capturing the light-rail passages, ensuring that the light-rail train passage was accurately identified. The maximum vibration level is determined based on an arithmetic average of the 5 light-rail passages with highest recorded levels. Figure 2 is showing an example of the setup inside a dwelling.



Figure 2: Example of the measuring setup.

2.2 Low-frequency noise measurements

The low-frequency noise measurements have been conducted with two Sound Level Meters Brüel & Kjær Type 2250 and Type 2270 with microphones Brüel & Kjær type 4189. The measurements were conducted in accordance with "DEPA no 9/1997" and supervised by Lars Find Larsen, who is certified to undertake environmental noise measurements according to DS/EN ISO/IEC 17024.

The measurements were undertaken at 4 locations in the room. The result is presented as the average of the 3 locations most exposed to the noise. The measurements were done supervised meaning that the certified acoustician was observing the train passages and the surroundings during the measuring period as well as keeping a log.

3. Guidelines regarding vibrations and low-frequency noise

The guidelines for vibration and low-frequency noise are specified in "DEPA no 9/1997".

3.1 Vibrations

The vibration limit value for the measured locations is 75 dB(KB), which according to the guideline in applies to day, evening and night in residential areas and to evening and night periods in areas for mixed use. During day period in mixed areas, the limit is less strict. The light-rail is operating under the same conditions during day, evening, and night. Therefore, the evening/night limit will be the most restrictive and hence governing. The measured vibrations shall be reported as accelerations with time weighting "slow" and weighted with the KB filter in the frequency interval of 1-80 Hz.

Table 2: Limit values for vibration comfort.

	KB-weighted acceleration level, L_{aw} [dB(KB) re. 10^{-6} m/s ²]
Dwellings in residential areas (day, evening, and night), kindergartens, etc. plus dwellings in areas for mixed use in the evening and night period (6pm-7am)	75
Dwellings in mixed areas in the day period (7am-6pm) and in offices, rooms for teaching etc.	80
Enterprises other than offices.	85

3.2 Low-frequency noise

According to the guideline, low-frequency noise shall be evaluated over a 10-minute reference period. This implies that the noise contributions from the light-rail vehicles passing shall be averaged over a 10-minute period. Therefore, the interval between the light-rail vehicles is important.

During daytime, 7:00 to 18:00, the interval between the vehicles is 7.5 minutes in both directions adding up to a maximum of 4 vehicles within a 10-minute period. During evening and night, the interval between the vehicles is increased to 15 minutes in both directions, implying maximum 2 passages within a 10-minute period. Between 18:00 & 19:00 and between 06:00 & 07:00, however, there is a transition between day and night time schedule, implying that 3 light-rail vehicles will pass within the 10 minute period.

The limit values for low-frequency noise are shown in Table 3.

Table 3: Limit values for low-frequency noise.

		Low-frequency noise level (A-weighted level: 10-160 Hz) [dB(A) re. 20µPa]
Rooms for occupation in dwellings, kindergartens, etc.	Evening/night (6pm-7am)	20
	Day (7am-6pm)	25
Offices, rooms for teaching and similar noise sensitive use		30
Other rooms in enterprises		35

4. Results

In the following the results from the measurement campaign are presented. Please refer to appendices for elaboration.

4.1 Vibrations

The maximum vibration level for each location is determined in accordance with "DEPA no 9/1997" as an arithmetic average of the 5 light-rail passages with highest recorded levels. The maximum level for each measured location is given in Table 4.

Table 4: Maximum vibration levels for each measurement location.

Address	Vibration levels dB(KB)
Stadionvej	77,3
Middelfartvej	73,1
Vestre Stationsvej	72,5
Kærlandsvænget	65,9
Østre Stationsvej	76,1
Nyborgvej	71,3
Hotel Odeon	62,8

It is observed from Table 4 that the vibration level in two of seven dwellings exceeds the threshold value of 75 dB(KB), cf. Table 2.

The results for all the measured light-rail passages in both tracks at each location are presented in Figure 3.

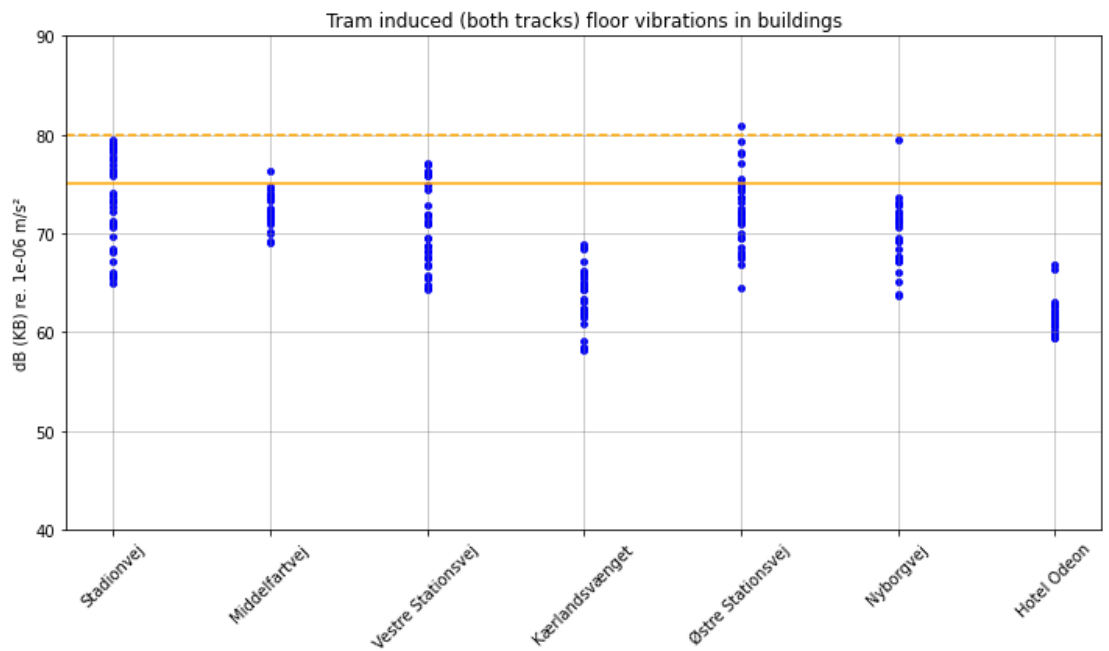


Figure 3: The measured vibration level in dB(KB) inside the 7 dwellings. The threshold of 75 dB(KB) shown with solid orange line and 80 dB(KB) with dotted orange line.

Table 5 shows the percentage of light-rail passages during the measurement campaign that is above the specified threshold.

Table 5: The percentages of light-rail passages recorded during the measurements that are above the thresholds.

Address	Above threshold 75 dB(KB) [%] (evening/night) (closest/furthest track)	Above threshold 80 dB(KB) [%] (day) (closest/furthest track)
Stadionvej	69/6	0/0
Middelfartvej	0/6	0/0
Vestre Stationsvej	27/13	0/0
Kærlandsvænget	0/0	0/0
Østre Stationsvej	44/0	6/0
Nyborgvej	7/0	0/0
Hotel Odeon	0/0	0/0

4.2 Low-frequency noise

The results from the measurements of low-frequency noise are presented in the following.

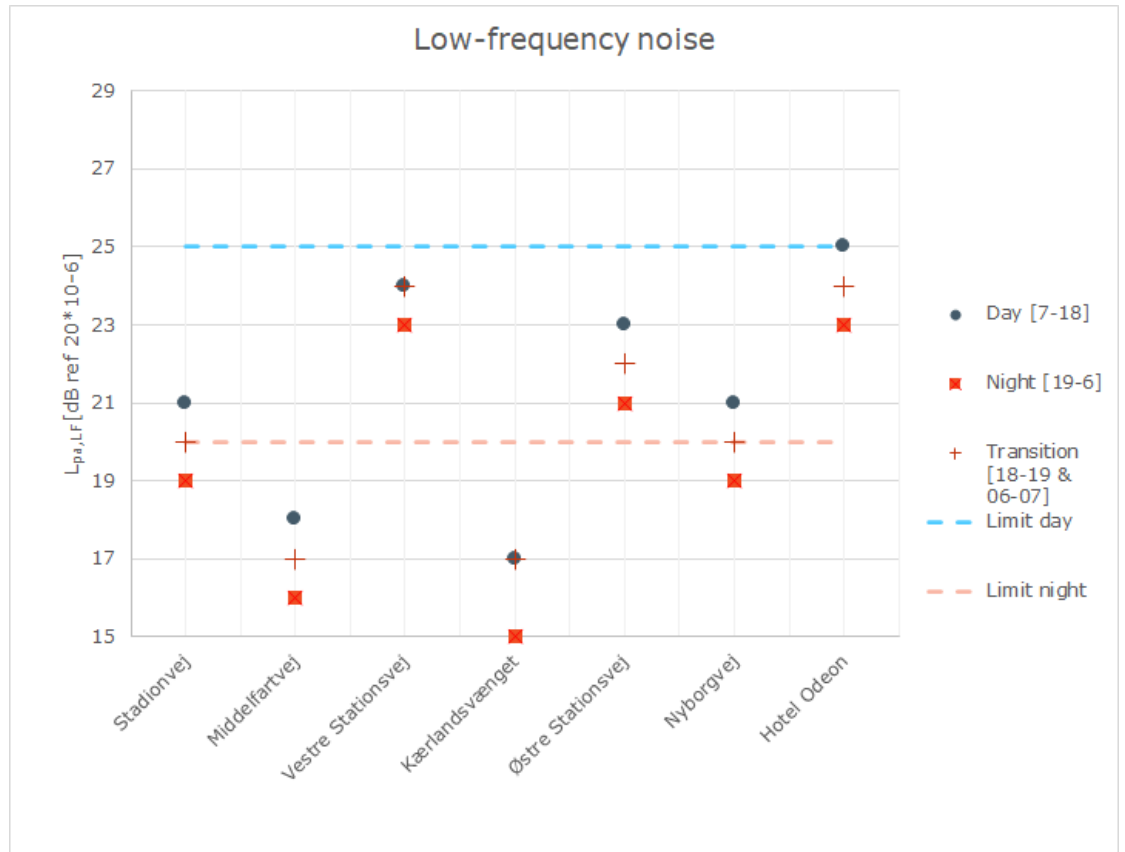


Figure 4: *Low-frequency noise in the daytime, night-time, and the transition period where both operation of the light-rail and positioning of light-rail vehicles going into or out of operation.*

It is observed that none of the locations have exceedance of the daytime threshold. In three of seven locations the measured low-frequency noise level is above the night-time threshold and correspondingly, in the transition periods, in three of seven locations levels are above the night-time threshold.

4.3 Measurements at Hestehaven

Results collected from the permanent vibration monitoring station at Hestehaven for the period from May 8, 2023 to May 17, 2023 are shown in Figure 5. Correspondingly, in Figure 6, results collected in the period 1st June 2022 to 5th June 2023 are given.

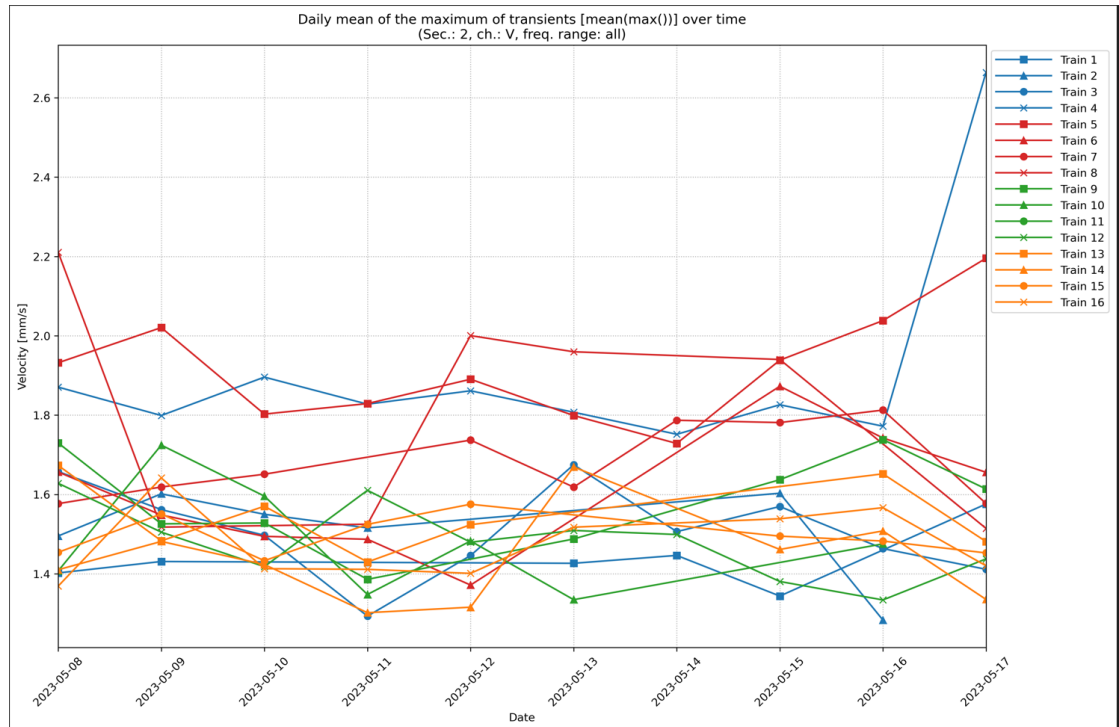


Figure 5: Vibration velocity [mm/s] at Hestehaven during measurement campaign 8.5. - 17.5., 2023.

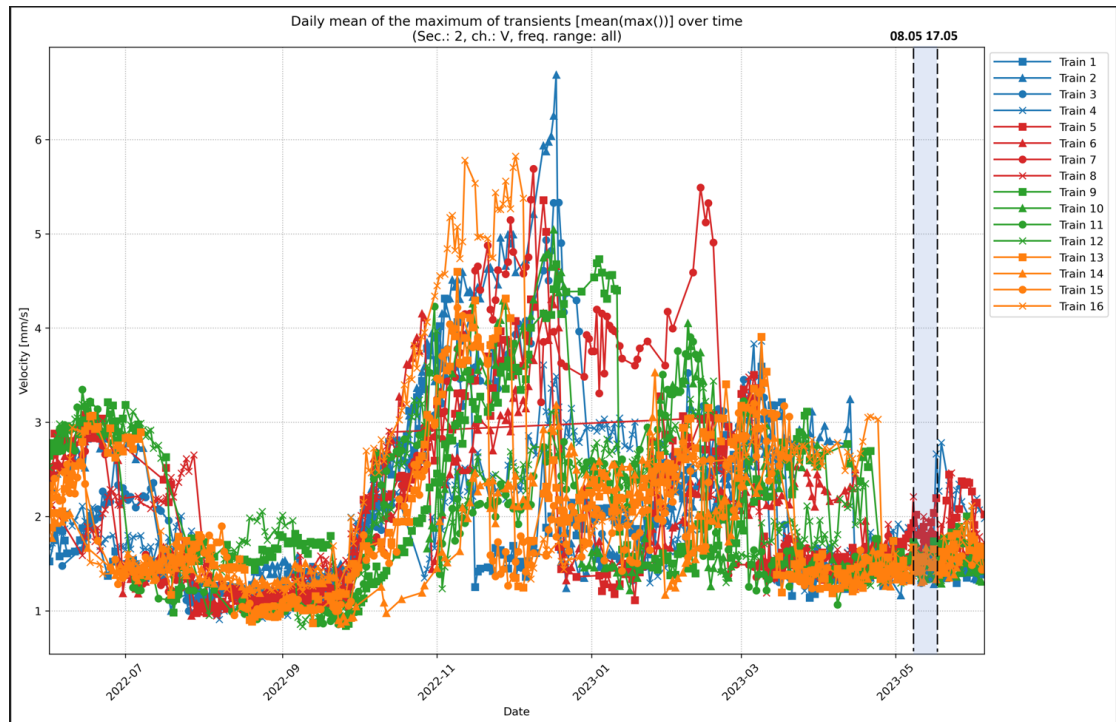


Figure 6: *Vibration velocity [mm/s] at Hestehaven from June 1st, 2022 until beginning of June 5th, 2023. The current measuring campaign is marked in blue.*

Appendix A – Measuring reports for vibrations

Appendix B - Measuring report for low-frequency noise
