Ground-Borne Vibration from Manchester Metrolink

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Abstract. The Trafford Park Line extension to the Manchester Metrolink light rail system included a planning condition to control the ground-borne noise from operating trams within a building in ITV's studios on Trafford Wharf Road. To determine the expected levels of vibration and noise within the studios, a series of vibration measurements and predictions were carried out during the detailed design stage of the project. These included source vibration measurements on the existing Metrolink network and ground vibration propagation measurements on site. A trailer-mounted sinusoidal vibration source was used in order to quantify the complete propagation from the source to studio, together with the resulting re-radiated noise. This paper describes these measurements and the subsequent analyses and assessment carried out to determine the anticipated ground-borne noise levels within the studio.

Keywords: Light rail · Ground-borne vibration · Ground-borne noise

1 Introduction

The Trafford Park Line (TPL) extension to Manchester Metrolink light rail network includes a section of new track alignment outside ITV's television studios in Trafford Park (Fig. 1). The studios are where the iconic Coronation Street television drama is filmed and include outdoor sets and indoor studios. Approval for the TPL was granted with a planning condition imposed to limit the tram-generated ground-borne noise inside ITV's Studio 4 building at a distance of approximately 32 m from the TPL.

This paper describes the measurements and analysis used to resolve the practical challenges of the project and hence assess the ground-borne noise within the internal studio area.

2 Planning Conditions

Planning Condition 10 [1] for the project is designed to mitigate the ground-borne noise due to trams in Studio 4 using the Noise Rating (NR) curve 25 L_{Fmax} as defined in BS 8233:2014 [2]. A time constant of 1/8 s (0.125 s) is indicated by the letter 'F' for 'Fast', together with a maximum level.

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Fig. 1. Aerial view of site

3 Methodology

The methodology to determine the likely ground-borne sound levels was as follows:

- Source vibration: measurements of vibration from the existing Metrolink system;
- Propagation: on site measurements; and
- Response: on site measurements of floor vibration and the resulting noise.

3.1 Source Vibration

Tram vibration source data were obtained from measurements by others on the existing Metrolink alignment at Merrill Street as part of a previous project (2nd City Crossing Project). At both Merrill Street and the future alignment outside Studio 4 the tracks comprise embedded rail with Ri59 section and Vector Boot encapsulation. Measurements were made of 'Single' Metrolink trams (2 vehicles, 3 bogies) travelling at speeds of between 23 and 37 kmh^{-1}.

The vibration acceleration data were re-analysed for a maximum level with a 'Fast' time constant to match the Condition 10 limit (Fig. 2). Individual tram passes are identified as blue lines and the spectrum with the highest level as a dashed pink line. Because of the short time window, the spectral information is poorly defined below the 40 Hz one-third octave band. For similar reasons the NR curve is defined, for the purposes of the limit criterion, down to the 63 Hz octave band.

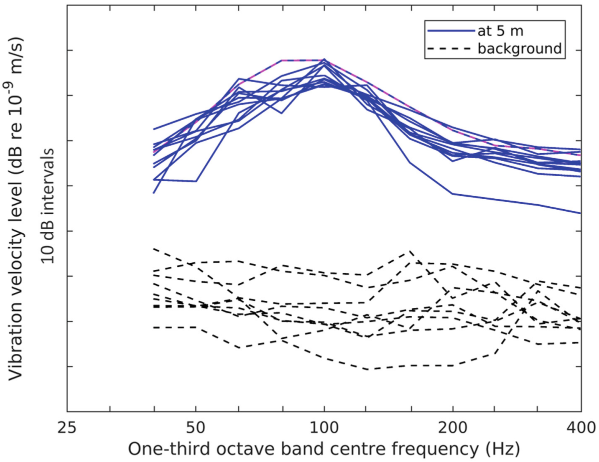

Fig. 2. Measured vibration spectra corresponding to L_{Fmax}

3.2 Propagation

To provide data on the vibration propagation between the prospective alignment on Trafford Wharf Road and Studio 4, measurements were made using a trailer mounted vibration source. Other vibration sources were considered, e.g. an impact hammer, but due to the distance between the alignment and the building, and the propagation characteristics at this location, a larger vibration source was required.

The 'MiniVib' trailer (Fig. 3) was used to create vibration in the ground at three positions along the TPL alignment to represent the approximate length of a 'Single' tram. Vibration excitation was generated in the form of a swept sinusoidal input with frequency linearly increased from 8 to 355 Hz over a period of 40 s, with a force of up to approximately 27 kN. The sweeps were repeated until 10 complete measurements were achieved without extraneous vibration affecting the integrity of data. Background vibration levels without the MiniVib operating were measured at the beginning and end of each set of sweeps.

No valid force signal was available and therefore the use of the Force Density Level/Line Source Transfer Mobility [3] method of vibration prediction was precluded.

During these tests the vibration response was measured outside of the studio in the vertical direction at distances of 5 m, 17 m, 22 m and 32 m from the source. The 32 m distance was adjacent to the external wall of the Studio 4 building. Inside the studio, the vibration response was measured in the vertical direction at three positions, together with measurements of sound at 1.5 m above the floor at a position adjacent to one of the vibration response measurement positions.

Fig. 3. MiniVib trailer

Figure 4 presents a comparison of the vibration levels measured inside the studio at the three positions (labelled M1, M2 and M3). The measurements were repeated for the operation of the MiniVib vehicle at the three positions along the prospective alignment (labelled VP1, VP2 and VP3). For each spectrum, the presented levels are the average of five frequency sweeps. Also included for comparison are the measured background vibration levels without the vehicle operating. The background vibration was thought to be due to the airborne excitation of the building by the noise from the MiniVib. The measured vibration is significantly higher than the background vibration (greater than 10 dB difference) in the frequency bands from 10 Hz to 100 Hz. At frequencies higher than 100 Hz, the measured vibration is not reliably determinable above the background vibration. At these frequencies, the low level of measured vibration during a MiniVib sweep was due to either the magnitude of the force that the MiniVib vehicle can input into the ground or the low propagation of vibration.

Also presented in Fig. 4 are the average of the results from the nine measurements inside the studio (three vehicle positions and three measurement locations) and the average of the same measurements outside the studio (thick black lines). These are similar in level across the frequency range and indicate that there are little or no coupling losses between the ground outside the studio and the floor of the studio.

To quantify the vibration in the studio, the difference in vibration level was required between the studio and the position 5 m from the alignment (Fig. 5). As expected, there is an approximate linear decay trend for most frequency bands. The lower frequencies also decay more slowly than the higher frequencies; this is due to the damping losses in the ground. Also, the higher spectral bands are adversely affected by the background vibration (black line).

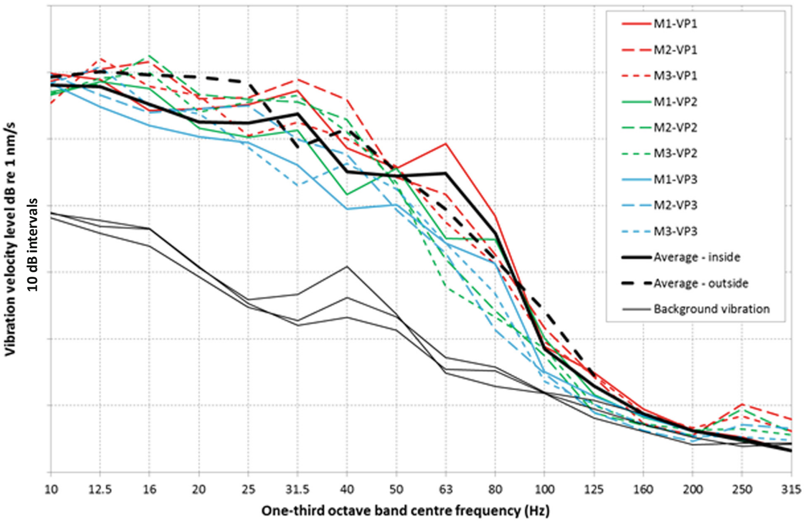

Fig. 4. Measured vibration inside and outside Studio 4

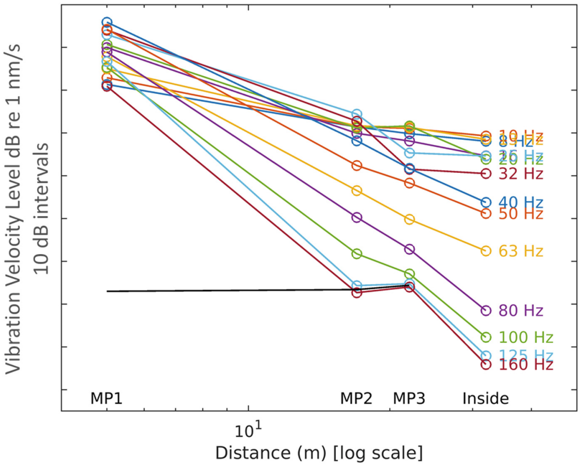

Fig. 5. Measured level difference - source to studio

3.3 Prediction of Sound Level from Floor Vibration

Figure 6 averages the sound level spectra and the studio floor vibration spectra (Fig. 4) in octave bands in order to establish a relationship between the sound level (L_p) and the floor vibration velocity level (L_v). Because of the masking from background levels, only data in the 31 Hz and 63 Hz bands provide a measure of the constant of proportionality between the sound and the vibration velocity. In this case this is approximately −27 dB and this is the relationship used in the subsequent predictions.

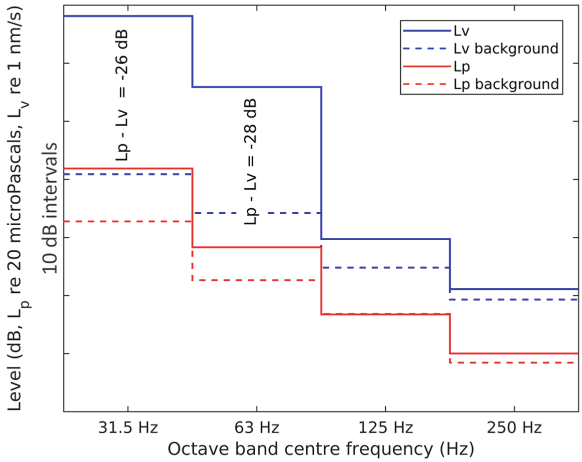

Fig. 6. Sound and floor vibration averaged in octave bands

4 Results

The predicted ground-borne noise (L_{Fmax}) in the studio from the passby of a 'Single' Metrolink tram travelling at the track design speed of 48 kmh^{-1} is presented in Fig. 7, together with the NR 25 curve. The highest level is in the 63 Hz octave frequency band where the tram-generated ground-borne noise is predicted to be 49 dB L_{Fmax} (approximately 6 dB lower than the NR 25 curve). In the other third octave frequency bands, it is more than 6 dB below the curve. Therefore the predicted L_{Fmax} from a 'Single' tram was not expected to exceed the NR 25 curve.

Higher levels of ground-borne noise inside the studio are expected if a 'Double' Metrolink trams passes (comprising four vehicles and six bogies); or two trams pass Studio 4 at the same time, travelling in opposite directions.

The main sources of uncertainty that affect the predicted sound level in the 63 Hz octave band are:

- The variation of low frequency noise inside the studio, due to acoustic modes and the long wavelengths involved, may lead to a variation of sound level despite the generally high degree of acoustic absorption in the studio. This variation was estimated to be between 3 and 7 dB based on measurements carried out by ITV.
- The source vibration used was measured from trams operating on the existing network with nominally good track. If higher rail roughness should develop on the track outside Studio 4 compared to the track on which the source vibration was measured, this may lead to higher levels of sound than have been estimated. This source of variation should however be controllable by rail head grinding should the noise, at any stage, increase to a level approaching the NR 25 limit.

These uncertainties resulted in a risk that the predicted levels could exceed the NR 25 limit in some operational cases.

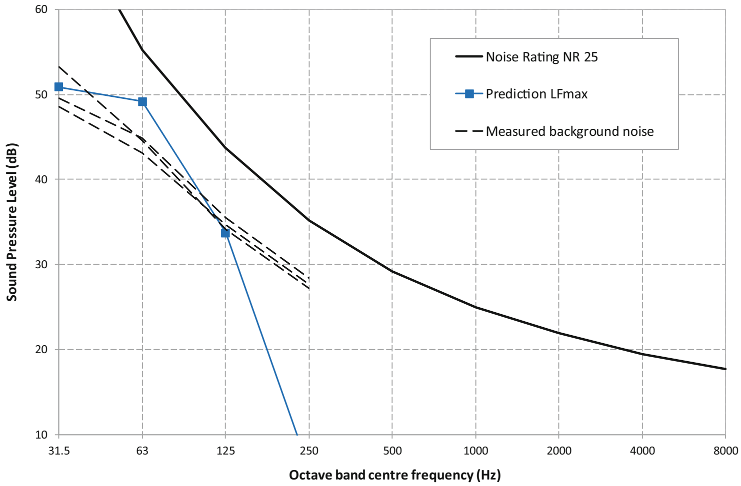

Fig. 7. Predicted L_{Fmax} octave-band sound levels compared with the NR 25 limit curve

5 Mitigation

To address the risk of exceeding the NR 25 limit, mitigation options were investigated, which included:

- Operational procedures (to prevent two trams passing at the same time);
- Speed restrictions; and
- Vibration isolating trackforms.

The project chose to implement a vibration-isolating trackform (a floating slab track) into the length of track outside the ITV studio. The design comprised a resilient mat (30 mm thickness, 0.01 N/mm^2 dynamic bedding modulus) under and to the sides of the TPL standard embedded rail track slab (420 mm depth) to form a system with a natural frequency of 15 Hz. With this design a vibration reduction of 10 dB was predicted at 63 Hz. Transitions of 15 m length were included between the floating and non-floating sections of track, with half mat thickness. Where required, ducting and connections to chambers within the slab were isolated with the same resilient mat.

Due to the additional low frequency noise radiated by the floating slab track compared to standard track, it was also necessary to consider the trade-off between the ground-borne noise in the studio and the airborne sound at the adjacent outdoor sets. As a result, the length of vibration isolating track was optimised to minimise these conflicting requirements.

6 Summary

Ground-borne noise from passing trams on the Trafford Park Line extension to the Manchester Metrolink system has been predicted within ITV's Studio 4 to assess against the relevant limit within the planning conditions.

Due to the distance between the track and the studio and the characteristics of the ground at this location, a vibrating trailer was used to quantify the entire propagation path from source to receiver. These propagation measurements were combined with vibration source data obtained from an existing line of the Metrolink system.

Using worst-case tram source vibration data, it is predicted that the likely ground-borne noise impact of a 'Single' (two vehicle) Metrolink tram passing at design line speed outside of the studio on Trafford Wharf Road would not exceed the required limit of Noise Rating curve NR 25 L_{Fmax}.

It was identified that there was a risk that the limit would be exceeded if:

- The uncertainties in the predictions were allowed for; and
- Adjustments were applied to account for the passby of a 'Double' tram and two trams passing at the same time while travelling in opposite directions.

The uncertainties included the variation of low frequency noise around the studio due to acoustic modes and the long wavelengths involved and the levels of rail head roughness.

Mitigation in the form of operational procedures to prevent two trams passing at the same time, speed restrictions, and vibration-isolating trackforms were investigated and their effectiveness quantified. The project chose to implement a vibration-isolating trackform (a floating slab track) into the length of track outside the ITV studio.

References

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