Proceedings of the Institute of Acoustics

NOISE AND VIBRATION FROM LUDGATE RAILWAY WORKS

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1 DESCRIPTION OF THE WORKS

There has long been a need for a north-south rail line across London avoiding the need for passengers to change stations. The lack of a crosslink resulted from the different railway companies all building their own separate terminus stations and the situation was made more difficult with electrification when incompatible systems (overhead wire and third rail) and different voltages were adopted by the regional railways. In 1987 British Rail placed before Parliament a Bill to re-open the old Snow Hill tunnel, demolish the existing Holborn viaduct terminus station and associated elevated railway and to build a new rail link between Blackfriars Station and the tunnel entrance incorporating a new low level station (St Paul's Thameslink). At the same time they started design work on new dual-voltage rolling stock capable of running off both third rail and overhead electrical supplies. The resulting works also released some prime building sites with the opportunity of direct rail access to the north and south. A general plan showing the proposal is given in Figure 1.

2 ENVIRONMENTAL IMPACT OF THE RAILWAY WORKS

At the time the Bill was being considered there had been little new mainline rail construction for many years and certainly nothing on this scale in the City of London. The most recent relevant experience had been with new London Underground tunnels and the Docklands Light Railway. Arup Acoustics was asked to provide support information for the Parliamentary Bill on noise and vibration from the demolition and construction works and in the longer term, the operational railway.

Fortunately the proposed new section of railway was in a commercial part of the City and there were few residential units in the vicinity. Apart from those premises that would actually be demolished there was one main office block at the junction of Ludgate Hill and Seacoal Lane that might be adversely affected, and the occupants of which had expressed concern. Particular attention was paid to the noise and vibration impact on these premises, though it was recognised that there could also be an impact due to the re-opening of the Snow Hill tunnel.

In the absence of any recognised guidance on the acceptable levels of noise and vibration from railway trains affecting office buildings, the first step that was taken was to establish existing levels. The office block was some 30 metres on plan to the side of the nearest tracks which were on an elevated brick arch structure with a steel bridge over Ludgate Hill. The facades overlooking the railway were therefore subject to noise from the existing trains using Holborn Viaduct Station and in particular the rail squeal from the curved track at the entrance to the station.

Initially a survey of noise and vibration levels was carried out at pavement level outside the office block in Seacoal Lane. This gave an overall indication of levels - see Table 1. The new railway was intended to pass close to the basement of this building, with the nearest tracks within 10 metres of the foundations. A simple comparison with other data measured within 10 metres of existing railway tracks in London indicated that vibration input to the building was likely to increase. Whether this was likely to be perceived as structural vibration within the building would depend on the structural response but it was considered likely that there would be sufficient energy in the audible frequency range for trains to be heard as a rumble. The indication was therefore that some noise and vibration control features would need to be included in the railway design.

3 INVESTIGATION OF NOISE AND VIBRATION CONTROL TARGETS

For vibration it was considered appropriate to use BS6472 (Reference 1) to establish firstly whether vibration would be perceptible and secondly whether it would be acceptable in an office environment. Based on the simple external vibration survey it was considered that existing vibration impacts might be perceptible but these would represent the first target for the new Railway Works since this would effectively leave the situation unchanged. A more detailed investigation was subsequently carried out with the permission of the occupants of the office block.

Arup Acoustics carried out a vibration survey using pairs of accelerometers adjacent to a column and at mid-bay in the building at 3 upper floor levels and in the basement of the building. The main purposes of this study were to establish absolute floor vibration levels due to existing trains and other environmental inputs; attenuation with distance up the building and the amplification due to the floor response. A noise survey within the building was carried out independently by the occupant's own acoustic consultant and it was agreed to exchange results from the two surveys.

The office block was a reinforced concrete structure with cast-in-situ concrete floors and raised office flooring. The windows overlooking the railway were double glazed with a deep cavity and the mechanical services had been designed in order to meet NR35. Existing trains could not be felt (as is supported by a comparison of typical measured spectra with BS6472 threshold of perception (Figure 2)) and had little effect on internal noise levels, though the rail squeal and characteristic rail joint noise could be clearly identified at positions close to the windows in the facade overlooking Seacoal Lane and the railway viaduct.

Existing vibration inputs were low and reliable signal-to-noise was only possible up to around 20Hz. Some general conclusions could be drawn, however, for example the amplification at mid-bay compared to a location close to a column (see Figure 3).

4 NOISE AND VIBRATION CONTROL

The new railway would be constructed in a concrete box at ground level and it was the intention to reinstate Seacoal Lane on top of the railway box. There was therefore unlikely to be any airborne noise problem since there would be a substantial reduction compared to the existing situation.

As a general precaution throughout the length of the enclosed railway a maximum of 300mm concrete was specified for the box construction.

It was also decided that the rail would be all-welded track throughout this section. In practice however it was necessary to include a crossover near the end of the platform to allow trains to change over tracks. This was thought likely to be a source of additional vibration and structureborne noise but it was not clear whether this would be any differentt from an ordinary rail joint. A study was therefore carried out at London Bridge Station where a similar crossover was identified at the platform end and also including jointed track for direct comparison. This location was not ideally suitable for the base case vibration data since, whilst it had the right track, train speeds and the same existing rolling stock, it too was on an elevated brick arch structure. The coloration of the brick arch response was minimised by attaching the transducer to the crown of the arch. Figure 4 shows that the data for the rail joint and the diamond crossover were sufficiently similar in spectral content to be able to go to another location for absolute vibration measurements at grade. East Croydon was chosen because of the access to a similar rail joint close to the end of the platform where trains of the existing type would be travelling at similar speeds to those proposed for Ludgate. The baseline data from this study was used for the railway design. This still left the uncertainty of the new dual voltage train stock which had yet to be built but we could not wait for this, and it was felt that the new stock, with low unsprung mass and air suspension, would, if anything, be better than existing stock, leaving a small margin of comfort in the design.

Figure 5 shows the predicted vibration levels at the base of the office block, based on the East Croydon data, compared to measured existing levels.

The overall conclusion as far as the existing building was concerned was that low frequency vibration from the new trains was unlikely to be perceptible but that there was a small risk of structureborne noise being evident. A number of options were considered to control this but the final decision was taken to incorporate resilient under-sleeper pads for the length of track alongside the office block. These comprise a resilient pad attached to the sleeper before laying the track in conventional ballast as shown in Figure 6. The attenuation that was to be expected from this system is also shown in Figure 6. It was also felt that the loading of the ground by the new track support structure would also provide some additional restraint to vibration. Naturally, care was also taken to ensure that no part of the railway box structure came into contact with the structure of the office block. In practice this was quite difficult to achieve because of the details of pavement, stairs, etc in this area.

5 RESULTING OPERATIONAL NOISE AND VIBRATION LEVELS

The railway has now been operational for some time and the St Paul's Thameslink Station officially opened recently. The opportunity was taken to go back to the base of the office block and repeat the original vibration survey. The results of this are shown in Figure 7. There have been no adverse comments from the occupants of the office block and from the data in Figure 7 this would not be expected since the corresponding vibration at upper floor levels would be below the level of perception and in the audible frequency range the noise levels would be less than NR30.

6 OFFICE DEVELOPMENTS

During the design of the Railway Works consideration was also given to the effects on proposed office developments that would be made possible by the land released adjacent to and over the Railway. It was felt that the measures already incorporated in the railway would be as much as was practically possible but that modern lightweight buildings with large spans over the railway would need to incorporate their own vibration and noise attenuating features.

A number of office developments have been proposed along the line of the railway. One of these office blocks, 200 Queen Victoria Street, was designed to be above and to the side of the new viaduct effectively leaving an elevated open sided tunnel. We considered this would increase noise levels at the offices on the other side of Blackfriars Lane and have proposed that this be enclosed as shown in Figure 8. All the office developments will incorporate some form of resilient bearings. The first office to proceed is 100 New Bridge Street which is located mainly to the south of the St Paul's Thameslink Station where the railway comes out of the ground on its way up to Blackfriars Station. A detailed analysis of this building structure was carried out and the developer was keen to ensure very good standards particularly with regard to vibration. The study showed that it would be just possible to achieve vibration levels to meet curve 4 of BS6472 for offices, but after a demonstration using an electro-dynamic shaker driven by railway vibration tape recordings to simulate these levels of vibration in an office building, the developer called for better standards. The only practical way to achieve this was to use a very low natural frequency system, below the main floor frequencies. For a combination of this and other engineering considerations a 3.5Hz spring system was chosen. This building, which is currently on site, is believed to be the first in the United Kingdom to be totally supported on springs. The springs are pre-compressed and the building erected on top. When the building loads are in place the springs will be released and the building allowed to float. We have measured data on vibration levels at pile cap level and are shortly to take measurements in the building just before the springs are released. It is hoped that this will enable us to assess what the building response would have been had it not been isolated and also, by comparison with measurements made after releasing the springs, to assess the insertion loss of the springs.

7 CONCLUSIONS

The Railway Works have been successfully completed and the combination of design features and new rolling stock has resulted in no significant increase in vibration and structureborne noise levels at the adjacent office block despite the new railway being much closer to the foundations. The earlier concerns have been allayed and the project has demonstrated that such works can be carried out without major environmental impact. Office developments above the new railway are now under construction and, with the additional vibration control features included in these designs it is confidently predicted that resulting noise and vibration levels in the new offices will also meet acceptable standards.

REFERENCE

1 British Standard 6472: 1984 'Evaluation of human exposure to vibration in buildings (1Hz to 80Hz)'

Event	Maximum rms vertical vibration velocity levels, mm/s
8 car trains, nearest tracks	0.05 - 0.08
4 car trains, farthest tracks	0.04
Background (road traffic)	0.01 - 0.02

TABLE 1: Measured overall vibration velocity levels on pavement outside office block in Seacoal Lane.

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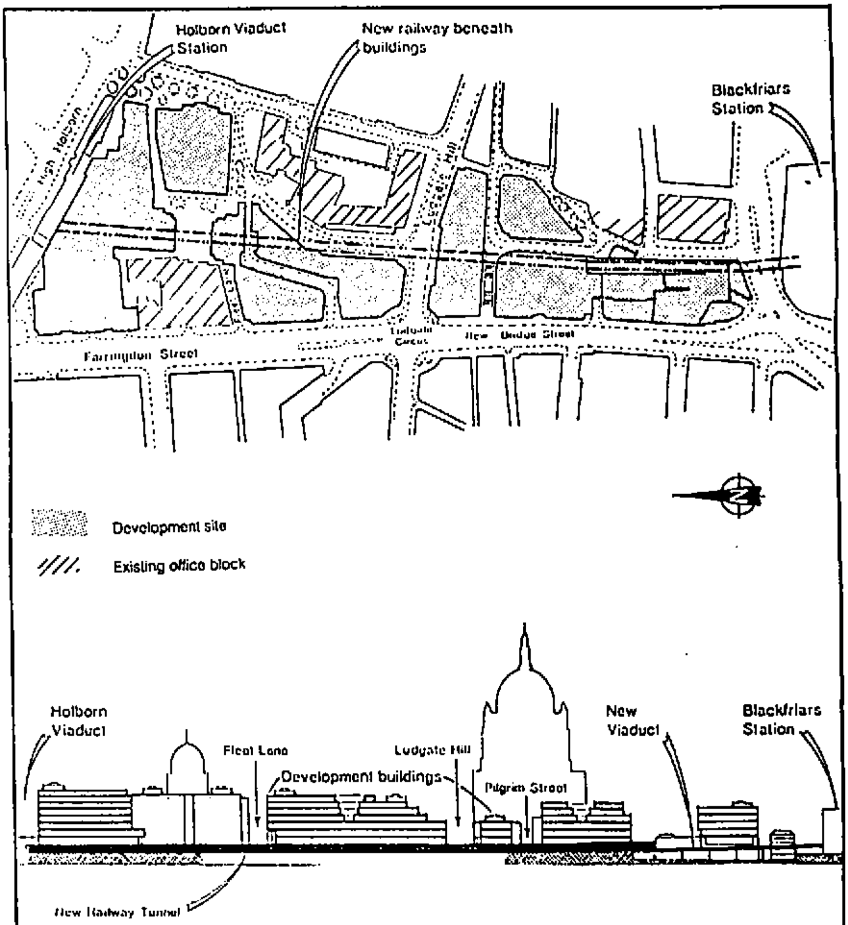

FIGURE 1: PLAN AND LONG SECTION OF PROPOSED LUDGATE RAILWAY WORKS SHOWING EXISTING OFFICES AND POTENTIAL DEVELOPMENT SITES

NOISE AND VIBRATION FROM LUDGATE RAILWAY WORKS

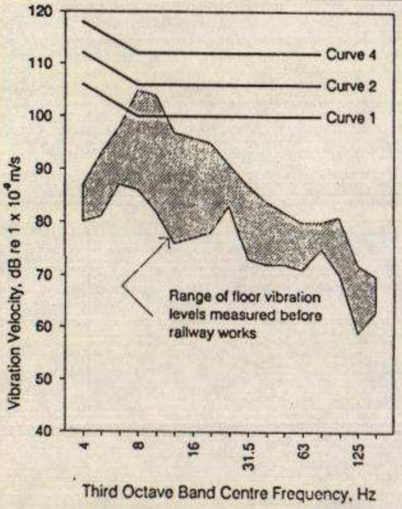

FIGURE 2: FLOOR VIBRATION LEVELS MEASURED IN OFFICE BLOCK BEFORE RAILWAY WORKS COMPARED WITH CRITERIA IN BS6472:1984

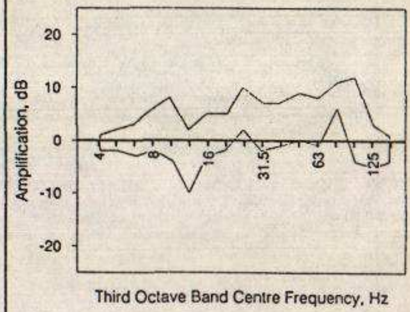

FIGURE 3: AMPLIFICATION OF VIBRATION AT MID-BAY COMPARED TO A LOCATION CLOSE TO A COLUMN

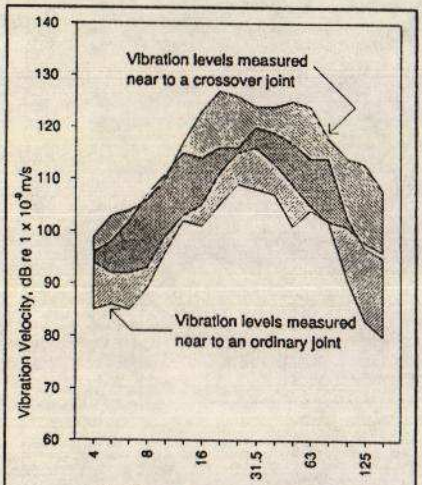

FIGURE 4: VIBRATION LEVELS MEASURED NEAR TO A CROSSOVER JOINT AND NEAR TO AN ORDINARY RAIL JOINT AT LONDON BRIDGE

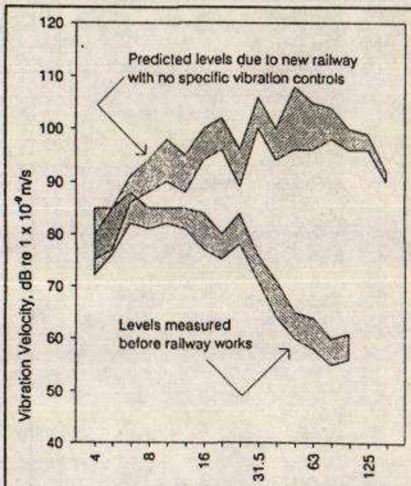

FIGURE 5: VIBRATION LEVELS AT THE BASE OF THE OFFICE BLOCK

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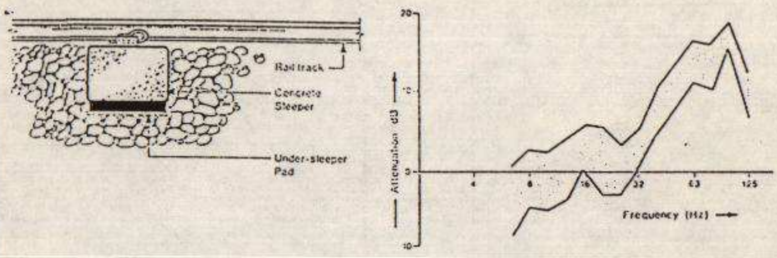

FIGURE 6: POSITIONING OF UNDER-SLEEPER PAD AND RANGE OF EXPECTED ATTENUATION

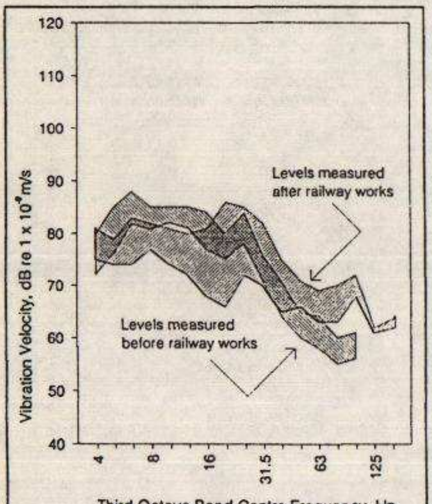

FIGURE 7: VIBRATION LEVELS MEASURED AT THE BASE OF THE OFFICE BLOCK BEFORE AND AFTER THE RAILWAY WORKS

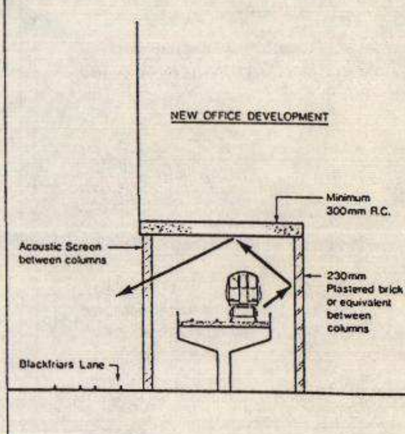

FIGURE 8: SECTION THROUGH AREA OF BLACKFRIARS LANE LOOKING SOUTH