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AIR RIGHTS BUILDINGS

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1. INTRODUCTION

The pressure on building land in major cities, problems with transportation infrastructure and the need to upgrade and refurbish the railway net work, have lead in recent years to the proliferation of so-called 'air rights buildings'. The British Rail Property Board realised that it owned the right to develop in the air above its properties, and by entering into agreements with property developers could sell this development space to finance railway and station improvements. Almost all the main railway terminals in London have or have planned such developments and we have been involved in many of these including the Broadgate Development at Liverpool Street Station, Victoria Plaza and No 123 Buckingham Palace Road at Victoria Station, No 1 America Square at Fenchurch Street Station, the new Waterloo International Terminal and associated office development, the proposed new Kings Cross Station and associated development and the new Thameslink railway at Ludgate and St Paul's Station, and associated office development.

Similar structures are now also appearing over major roads.

All these developments present new engineering challenges, firstly in structural design with long span bridging decks and restricted areas for foundations and support columns, and secondly, as I will describe today, in terms of design to minimise noise and vibration impact.

2. THE ACOUSTICS PROBLEM

Figure 1 shows schematically the problem we are faced with.

I do not wish to cover airborne noise today since whilst this is an interesting topic in its own right, this can usually be controlled with existing materials, construction and specification. The two main issues are therefore vibration in the frequency range 0 - 80Hz and particularly the range 5 - 25Hz where primary structural responses occur which could be perceptible in the development with a risk of adverse comment from occupants, and vibration in the audio frequency range, ie above about 25Hz which could give rise to re-radiated low frequency structureborne noise. I will be considering these issues under the three headings of prediction, assessment and control.

3. PREDICTION OF VIBRATION AND STRUCTUREBORNE NOISE

In the majority of cases the source of vibration is already present and the first step is to quantify the source strength to form the input to a prediction model. In other cases, eg new railways and new trains, the source input has also to be predicted leading to further uncertainties.

The measurement of vibration from trains is in itself not precise because the ideal of a measure of force/time signature is impractical. Most sites at the early assessment stage when key decisions have to be made, eg whether to proceed with the development at all or the cost estimate of vibration control measures, are either cleared ground or possibly have some existing structures of uncertain foundation on them. Since a vibration measurement in the vicinity of the railway track can only be a measure of the response of the measurement point to the dynamic force input of the train and not an absolute quantification of source strength, care is needed in the selection of the measurement surface and mounting arrangement. I advocate either measuring on the unloaded ground surface, ie bonding the transducer mounting block directly to the surface, or measuring at the footing of a loaded structure provided that that structure is simple and well understood. The parameter we measure is the maximum rms vibration level during the passage of the train. Velocity is chosen because it can be compared both directly to vibration acceptance criteria and can also be readily converted into radiated sound pressure levels. The equipment used is either a Bruel & Kjaer Type 4370 or 8306 accelerometer fed via a Type 2511 Vibration Meter into a NEAS Type 830 Analyser or recorded on a TEAC FM tape recorder for subsequent analysis on the NEAS analyser. Such a surface measurement should only be used for an initial screening assessment and if either vibration or structureborne noise is predicted to be likely to be a problem a more definitive approach is necessary.

For buildings over railway structures the building load usually needs to be supported on a relatively few highly loaded columns, thus piled foundations are common. These normally require geotechnical investigation at an early stage of the project with trial boreholes at locations where the building is likely to be founded. By using oversized boreholes we have developed a technique for measuring vibration levels at a depth in the ground equivalent to the base of the piled foundation. A typical measuring arrangement is shown in Figure 2.

To predict vibration levels in floors of a building a simple finite element model is used to determine response frequencies and a digitized version of the measured train vibration signature is passed across the base of the model. This is usually done in conjunction with the structural engineer, and damping factors selected from data we have measured on a range of modern building types. This gives an estimate of vibration velocity levels at the natural frequency of a floor slab during passage of the train.

For structureborne noise the one third octave spectra from the NEAS analyser are read into a desktop PC for manipulation in a spreadsheet format. Initially we used published results for losses through a structure but we have gradually over the last five years been able to build up our own data bank of ground to pile, pile to column, column to floor, floor edge to centre bay factors and also coupling between structural elements and raised computer floors, partitions and suspended ceilings.

4. ASSESSMENT

Criteria for vibration control have been taken from BS6472 (Reference 1). For most mainline situations there are sufficient trains for the total vibration experience to be regarded as continuous and curve 4 has been used for general offices (Figure 3). For noise we have taken the view that noise due to passage of a train may be allowed to increase the ambient noise levels over those generated by mechanical services and external airborne noise sources by a small amount at low frequencies. We believe that some intrusion over background noise is acceptable, though this philosophy clearly relies on there being a reliable source of background noise. A typical permissable excess over a services background noise level of NR35 is shown in Figure 4.

In both cases we have tested these assessment criteria experimentally to satisfy ourselves as to their validity and also as an aide to demonstrating to a client what he will be getting for his money. For vibration we have played tape recordings of actual vibration signatures through an electrodynamic shaker attached to a floor slab and experienced the vibration in an adjacent mock-up office suite. For noise the same vibration signatures have been played through concealed low frequency loudspeakers in the presence of a separate artificial services noise source, both of which could be regulated to demonstrate various signal-to-noise ratios. Having carried out several such demonstrations I can vouch for the fact that it is possible to produce very realistic simulations which compare to actual noise and vibration as experienced in existing buildings near railways.

Comparison of predicted noise and vibration levels with these criteria therefore establishes the need for any modification of structural design or inclusion of attenuating features.

5. CONTROLS

To date we have found that it is invariably possible to design a structure that can contain vibration levels to be within the BS6472 Category 4 curve without 'vibration isolation'. This is done by adjusting floor natural frequencies, use of transfer structures as 'springs' and the separation of building structures from railway structures. One is therefore usually left with a residual structureborne noise problem in the 31.5Hz to 125Hz frequency range. In two cases we have been able to incorporate resilient undersleeper pads into the railway to reduce some of this high frequency vibration. Such measures usually do not provide enough attenuation and can be difficult and expensive to incorporate in existing track. The usual solution is therefore to support the new building on resilient bearings. In order to obtain useful attenuation in the audio frequency range it is normal to specify bearings such that an overall isolation frequency of the order of 10Hz is achieved. This can be achieved by proprietary natural rubber bearings incorporating steel load bearing plates or neoprene and textile reinforced composite pads.

To date we have had two exceptions to this. At Victoria the office development at No 123 Buckingham Palace Road is being supported on 7Hz natural rubber bearings because the predictions showed this would be necessary to achieve a high level of structureborne noise isolation and vibration levels were expected to be close to the category 4 limit and the structural analysis showed that a lower frequency bearing would also afford a small reduction in perceptible vibration. At Ludgate where one of the office blocks is to be built with the new railway running through its lower two floor levels and, despite the use of resilient sleeper pads, our analysis showed a 5Hz isolation system was required. This building is still in the design stage but it is likely that steel coil springs may be required to achieve this low isolation frequency and indeed a number of 3.5Hz springs have been installed where part of the foundations of this building had to be built at the same time as the new railway structure.

In addition to primary isolation of the building there are numerous secondary details to be resolved where services and other features cross the line of isolation with a severe risk of noise bridging. In practice these details can prove as time consuming as the primary bearing and support design.

6. SPECIFICATION AND TESTING

A performance specification is a simple way of procuring resilient bearings, but as these form an integral part of the structural design it is usual for detailed material and installation specifications to be developed in conjunction with the bearing supplier. The basis for specification is BS6177 (Reference 2) which also gives guidance on quality control and testing. The necessity for an installation specification is paramount where the bearings are supplied to a steelwork contractor who has no experience of such specialist products.

Protection of bearings on site and the prevention of bridging can almost be regarded as a full time task for one person throughout construction to handover.

The overall success of a project is determined by the final client reaction and commissioning tests to show, hopefully, that the recommended noise and vibration standards have been achieved. As with all engineering a cautious approach must be adopted until experience and confidence is built up. We have, therefore, taken every opportunity to monitor vibration levels throughout construction to check on how well the elements in the prediction chain can be defined. All vibration measurements on building sites are difficult since other temporary vibrations sources, temporary chocking and yet to be cleared bridging all influence test data. The best that can be hoped for is to measure everything and try and sort out trends and factual results from the noise.

In Figure 5 I have summarised some of the test data that we acquired at No 1 America Square from the time of the preliminary site visit three years ago to recent floor measurements on the structurally complete building with only cladding and fit-out to be completed.

7. PRACTICAL LESSONS THAT HAVE BEEN LEARNT

When this recent group of building projects started some five years ago we were short of experience in most areas - what to measure, how to measure it, acceptability criteria, prediction techniques, specification of materials, material testing and bridging. One of my main concerns was that decisions to resiliently support a structure, with a seven figure added cost!, were taken at an early stage on very little concrete evidence. We also had several projects running in parallel and experience gained on one project could not be used sequentially on the next.

What then have we learnt.

- Be consistent in the approach. We know that our measurement techniques may not stand up to rigorous scientific scrutiny but we have used these methods consistently and repeatedly and by correlation with what we feel and hear have a good understanding of what they mean.

- Clear definition of the problem. It is essential to gain the confidence and understanding of your client on a subject matter which is difficult to elucidate. We have found practical demonstration of levels in actual buildings to be a great help in this area but such demonstrations must be well planned and rehearsed. A poor demonstration could equally well wreck the project.

- Vibration is site specific. There are no general rules that can be applied with sufficient accuracy concerning distance from a railway at which isolation is necessary or the form it should take. A preliminary site survey is always therefore essential before advising a client as to the necessity for corrective action.

- There is very little practical variation in vibration response of modern buildings. We are often asked such questions as, is steel framing worse than concrete? or is a deep piled foundation better than a raft?. The simple answer is .....it depends! but where a problem is identified no one structural alternative will provide sufficient confidence of solution. A generalised building response is usually adequate at conceptual design stage.

- Build up a data base. We are now in the position of being able to screen a new site by a simple surface vibration survey and comparing this to data we have for other sites and the design solution we adopted there, ie is site X a Waterloo or a Victoria! such comparisons have proved invaluable but be wary! There will always be the exception to the rule and no data base is ever complete.

- Never underestimate the design complexities introduced by the use of resilient bearings. In cost terms alone the added cost of engineering a solution can be 2 or 3 times the material costs of the bearing. Equally never underestimate the time required by a resident engineer to supervise, inspect and protect the bearings and line of isolation during the construction phase. Contractors with no experience of such items will continually do what appears to be their best to destroy or bridge the bearings.

- The building and railway industries are both ultra conservative. Both are reticent about installation of control measures that have not been tried and tested elsewhere. Persistence is necessary to persuade clients to try new ideas and make progressive small steps forward.

8. REFERENCES

1 BS6472: 1984 Evaluation of human exposure to vibration in buildings (1Hz to 80Hz)

2 BS6177: 1982 Selection and use of elastomeric bearings for vibration isolation of buildings.

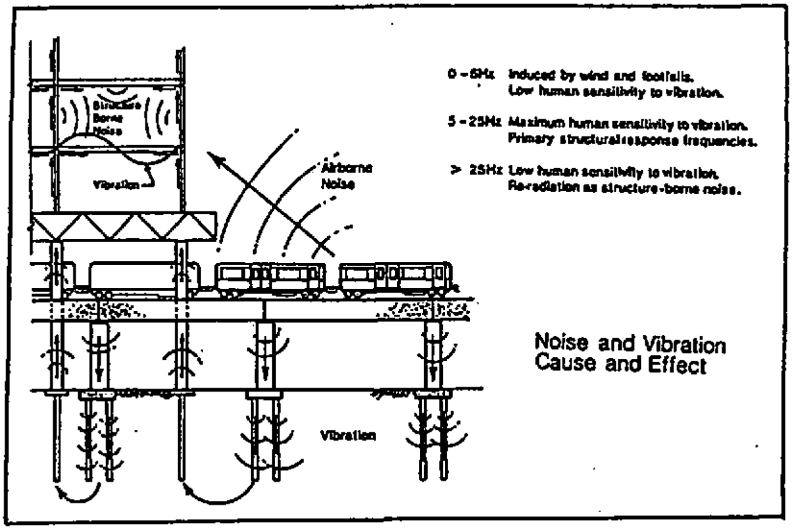

Fig. 1

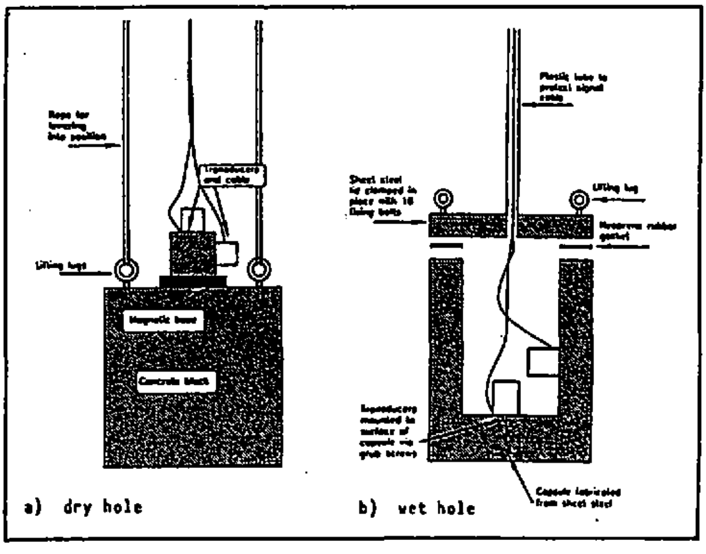

Fig. 2: Transducer mounting arrangement for borehole measurements

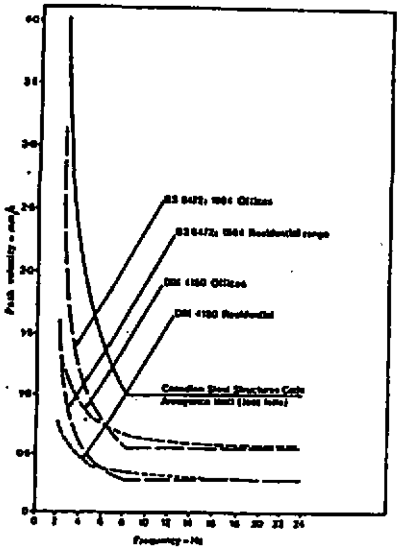

Fig 3: Floor vibration acceptance criteria

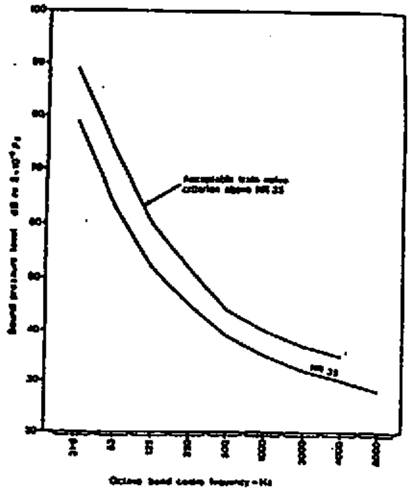

Fig. 4: Acceptability criterion for train noise in offices

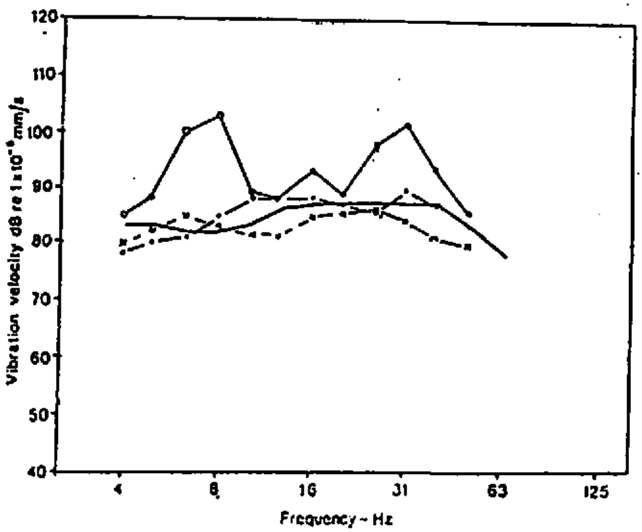

Fig. 5: Vibration spectra measured at No. 1 America Square