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Symphony Hall Birmingham - Railway Isolation and its Maintenance

Salle de musique Birmingham - Isolation et maintenance

Konzerthalle Birmingham - Schwingungsisolierung und Unterhaltung

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SUMMARY

The City of Birmingham's brief for the International Convention Centre and its Symphony Hall required that the facilities should rival the best in the world. The City Centre site is bisected by a main line railway tunnel. The project achievements included reducing the vibration from the railway to an extent which tested the limits of technology and workmanship. This paper considers the design of the railway vibration isolation system and its maintenance.

RÉSUMÉ

Le mémorandum de la ville de Birmingham pour l'édification de l'International Convention Centre avec salle de concerts indiquait que les aménagements devaient être parmi les meilleurs du monde. Or une importante ligne de chemin de fer passe en tunnel sous la zone à bâtir. Une partie de l'étude avait pour objet de réduire les vibrations dues au passage des trains à des valeurs pouvant atteindre les limites de faisabilité aussi bien techniques que professionnelles. Les auteurs présentent le projet et la maintenance du système d'isolation antivibratoire.

ZUSAMMENFASSUNG

Die Bestimmungen der Stadt Birmingham für das International Convention Centre mit Konzerthalle verfügten, dass die Einrichtungen der besten der Welt gleichkommen sollten. Der Tunnel einer wichtigen Eisenbahnlinie durchquert das Baugelände. Ein Teil der Projektleistung bestand darin, die Erschütterung durch Züge in einem Masse zu reduzieren, das zu den Grenzen des technisch und handwerklich Machbaren vorstiess. Der Beitrag behandelt Projektierung und Unterhaltung des Systems zur Schwingungsisolierung.

1. THE DEVELOPMENT

The Centre includes the 2,200 seat Symphony Hall and two Convention Halls of 1,500 and 300 seats respectively, each with raking floors. There are two flat-floored halls, of 2,700m² and 900m² respectively, that can be used for banqueting, exhibitions or 'pop' concerts. Six multi-purpose break-out and seminar rooms complete the facilities with associated registration, foyer, catering and support spaces.

Strategic planning began by locating the noise critical spaces away from the tunnel and its low frequency ground borne energy. No single means of attenuation could achieve the targets, so in addition to isolating the rail track, the design included heavy piled foundations with the top of the pile isolated from the ground. Further the noise critical halls were floated on elastomeric rubber bearings and were separated from the other buildings by jointing systems through both services and structures to avoid lateral vibrations.

Demanding construction procedures and inspection methods were overseen by a Management Contractor who was responsible for maintaining the integrity of the vibration isolation throughout the construction and installation phases. For optimum attenuation, each rubber bearing had to be tested and certified at works. Construction had to be planned to ensure even load transfer and each set of bearings had to be monitored to avoid under or over compression becoming a source of potential vibration bridging.

The acoustic performance is monitored through annual visual inspections of the railway track isolation and annual repeats of the acoustic tests to identify any degradation and its likely source.

The Symphony Hall has been acclaimed by performers and critics alike for its acoustic performance.

1.1 Location

The two and a half hectare city centre site for the International Convention Centre is bisected by the Monument Lane Railway Tunnel. This brick lined, twin track tunnel was cut in 1854 by Robert Stephenson. It now carries Inter-City trains from London Euston northwards via Birmingham New Street. The influence of the railway tunnel and the relative compactness of the site for 50,000m² development have both had fundamental effects on the planning arrangement for the eleven hall complex, see Figure 1.

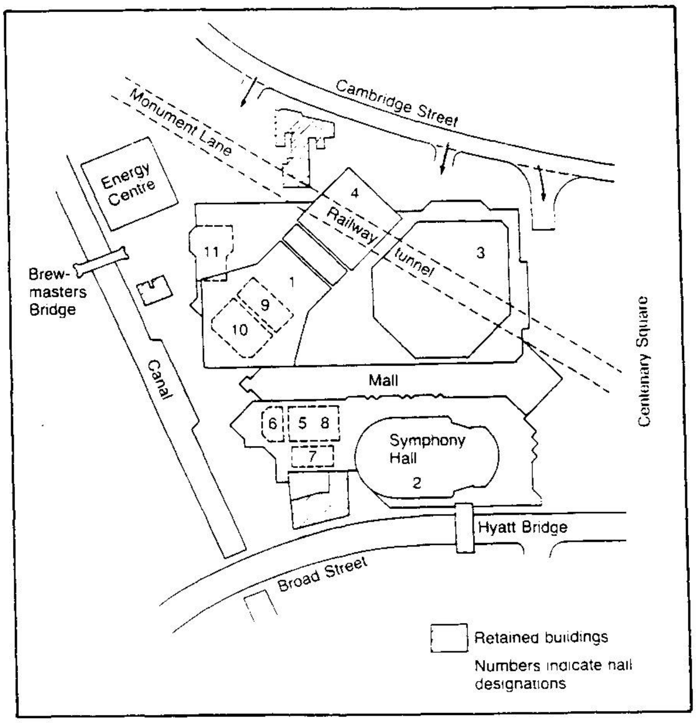

Fig.1 Plan: The Symphony Hall is located 35m from railway

2. RAILWAY VIBRATION

2.1 Vibration Investigation

Two surveys were carried out to determine vibration levels at various locations on and adjacent to the site.

The first concentrated on velocity measurements on the surface. One particular feature from the first survey was the concentration of energy in the 63Hz octave band. This arose because of the spectral emphasis within the train vibration. Results for a typical train are shown in Figure 2.

A second survey was arranged to improve understanding of the specific pattern of vibration propagation from this tunnel. A methodology was developed for vibration measurements within boreholes. Accelerometers were placed in them to sample ground response arising from compression and shear waves.

Examples of vibration velocity data from three boreholes are given in Figure 3. Although horizontal vibration levels were significant, the vertical component was found to dominate.

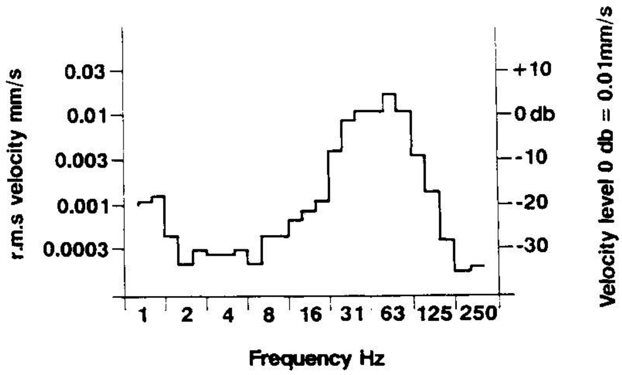

Fig.2 Typical ground vibration spectrum: measurements at 50m from tunnel.

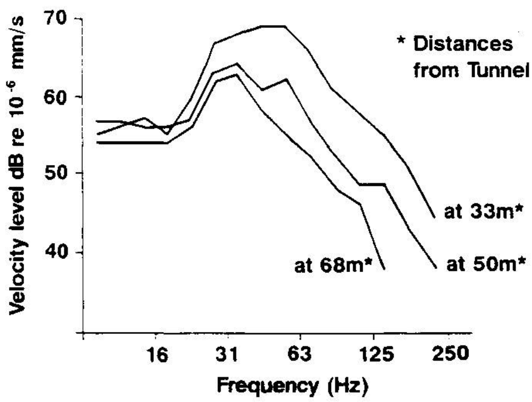

Fig.3 Borehole vibration data: Vibration at 33m, 50m and 68m from tunnel.

2.2 Planning Considerations

To achieve the number and size of halls on the constrained site, many of the halls had to be stacked either above each other or over support service space. A strategic approach had to be followed in order to protect the noise critical spaces, particularly in the Symphony Hall, Hall 1 and Hall 5. Substantial isolation at source, ie. at rail track level, was not practical.

2.3 Acoustic Targets

The Acoustic Consultant called for design work to be directed at the achievement of inaudibility of trains in the Symphony Hall. This demanding target meant that the low frequency ground borne vibration had to be attenuated and prevented from becoming significant structure borne energy that would result in noise.

3. ISOLATION AND ITS MAINTENANCE

The approach to isolate the halls from the low frequency ground borne vibration was to combine the contributions from seven different means. These are discussed below:-

3.1 Partial Track Isolation

Early discussions with Civil Engineers from British Rail revealed that although major track level isolation was impractical, they had plans as a part of their cyclic maintenance plan to relay the track and sleepers in the tunnel during the construction period of the Centre. This offered a chance for under-sleeper isolation to be added. A sheet material manufactured by James Walker Ltd, which had been on trial in North Wales, had provided close to 10dB attenuation in the 63Hz octave band. It was felt that perhaps 6dB to 8dB might be achieved in the tunnel. In view of the wish to minimise transmission to the site, it was agreed that the tracks should be isolated. On site measurements have confirmed that a useful benefit has been achieved and Figure 4 shows results from a test train before and after installation beneath one of the lines. This installation provided a general, site wide lowering of vibration levels.

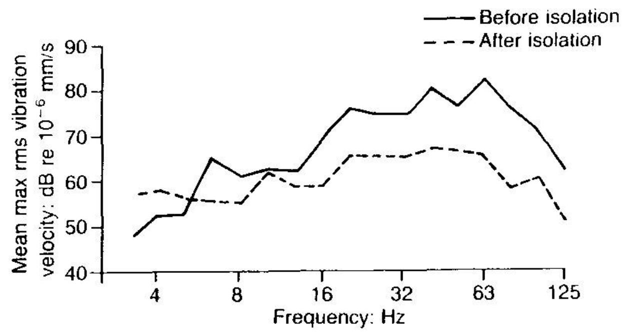

Fig.4 Rail isolation test train results: vibration velocity before and after isolation of rail sleepers.

It has been agreed with the Railways Board as part of the ongoing monitoring of the acoustic performance of Symphony Hall that periodic inspections of the track isolation will be allowed with the proper prior notice and safety provisions. These are jointly actioned by ICC Engineering and Ove Arup.

3.2 Distance

The Symphony Hall, being the most sensitive and noise critical space of the development, had to be located in the most favourable part of the site, ie. where the least ground borne energy existed. It was only possible to achieve just 35m to the Symphony Hall auditorium. At this distance the energy was beginning to decay and had become dominated by the surface wave.

3.3 Foundation Type

To maximise the attenuation, 'heavy' foundations were planned to support the noise critical halls remote from the tunnel. Foundations were arranged to take support only from the least mobile rocksand.

3.4 Pile Form

Large diameter bored piles cast into the Rocksand satisfied the 'heavy' foundation requirements. It was also possible to decouple the top of the Symphony Hall piles from the surface wave. Six metres was determined as a maximum realistic depth for the decoupling. Many materials were considered as sleeves at the top of piles to provide a mismatch against vibration coupling. To achieve the benefit, sleeving material needed to be highly compliant. It was eventually decided to use an air void around the top of the 120 piles needed to support the Symphony Hall. The piles were formed using concentric steel tubes as permanent formwork.

The pile boring was then advanced by continuing drilling down through the inner steel tube to form the rock socket. The pile and substructure arrangement is shown in Figure 5.

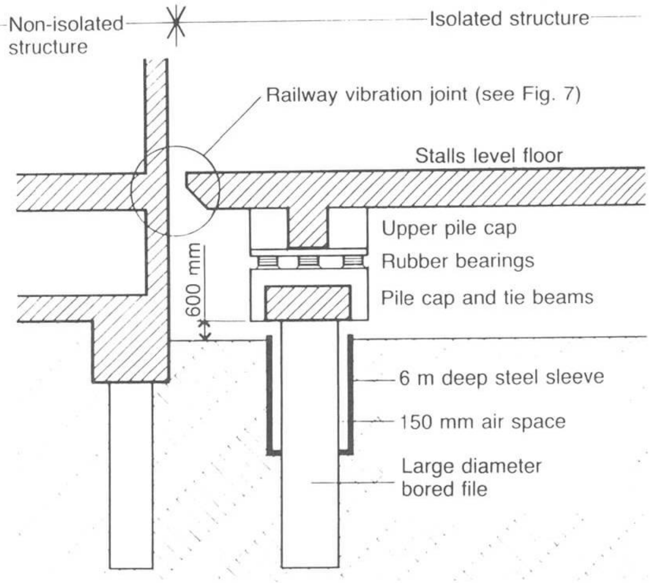

Fig.5 Isolated Symphony Hall foundations

Protective collars are in place to prevent the inadvertent introduction of any waste material into the void. Periodic inspections check the voids for the ingress of foreign material or water. Automatic leak detection alerts Engineering Staff to problems in the undercroft through the Building Management System.

3.5 Substructure

For the most noise critical halls, isolated superstructures are floated on twin layers of foundations, separated by a layer of bearings. Lower sets of beams restrain pile caps and they are always 600mm above the ground to maintain the integrity of ground isolation. Upper beam arrangements collect the superstructure loads together, see Figure 6.

Tight control on the geometry of air spaces is needed because, the stiffness of large expanses of shallow air space can lift the frequency. Also, the build up of resonances in voids can aid transmission sufficiently to have adverse effects on isolation. The complex geometry prevents powerful resonances occurring. The area of pile caps is limited to avoid excessive local coupling through air across the separating isolation bearings.

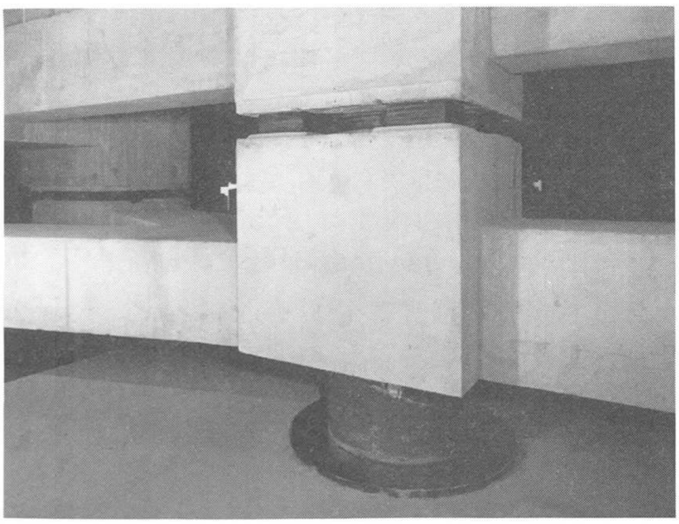

Fig 6. Symphony Hall foundations.

The integrity of the air space in the undercroft is protected both for acoustic requirements and for fire loading control. This requires that the undercroft remains a sterile area with the minimum of services and the prohibition of use for storage.

3.6 Bearings

Bearings separate isolated superstructures from their substructures. The bearings are steel plate-reinforced, natural rubber-based compounds manufactured and supplied by the Andre division of BTR Silvertown. A full programme of static and dynamic testing has been carried out, all bearings are numbered with individual static test certificates. Creep, ozonization, shear and durability assessments have followed the guidelines of BS6177: 1982.

Bearings are set onto levelled epoxy grout beds around a steel failsafe block. The construction followed the setting of the bearings on the epoxy and involved each array of bearings having a temporary edge shutter to allow the space between them to be filled with sand. A 50mm mass concrete slab the same size as the pile caps forms a permanent shutter to the upper cap. Each bearing array was monitored during construction. The mass concrete permanent shutter was also deemed to be a sacrificial slab should any bearing need removing or replacing. In fact, a few bearings were removed during commissioning to increase compression on some arrays.

3.7 Separation Joints

Where either isolated or non-isolated structure meet floated structures, a 50mm air space has been allowed. Total relative vertical settlement of as much as 12mm has been allowed across railway vibration isolation joints (RVJ's). Typically, joints have been designed to accommodate ± 6mm of lateral movement.

The elevational area facing the floated structure has to be limited, slabs and walls are generally chamfered to a 75mm deep nosing. A series of special bridging details deals with the need to carry people over the joint, achieve fire separation, and account for settlement and bearing creep without vibration bridging. Folded foam or ceramic blanket is used to achieve fire ratings within isolation joints, see Figure 7. For waterproofing or facing, low modulus sealants or dry resilient seals have been included.

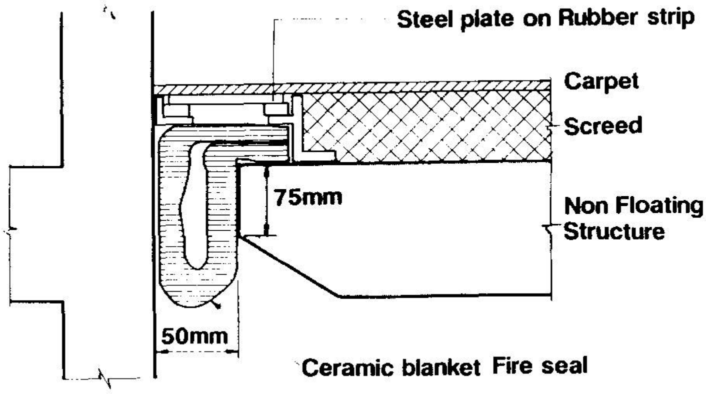

Fig.7 Railway vibration joint: isolation gaps separate all halls.

To ensure the original specification is protected through the engineering disciplines applied that prohibit the bridging of acoustic joints by rigid services runs during maintenance or modification work through a system of work permits and supervision.

4. CONCLUSION

Reliable measurements of any residual train noise are not realistic in relation to the very low levels of ambient sounds in the Symphony Hall. This underlines effectively the success of the isolation procedures and their continuing maintenance.