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THE ACOUSTIC DESIGN OF THE BRIDGEWATER HALL, MANCHESTER

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1 THE ACOUSTIC BRIEF

The requirement of Manchester City Council was for a world-class concert hall to host performances by international orchestras and choirs, the resident Hallé Orchestra and the other frequent users, the BBC Philharmonic Orchestra and the Manchester Camerata chamber orchestra. The brief required the hall to cater for the usual mix of non-orchestral events without compromising the acoustics for the primary function, the performance of classical, symphonic, choral and organ music.

A capacity of 2400 seats was specified. Unusually for a modern concert hall, the brief excluded, for cost reasons, the provision of elements to vary the acoustic.

2 THE AUDITORIUM ACOUSTIC

Design principles

The geometry is a hybrid of the classical 'shoebox' and the 'vineyard' forms (Figures 1 - 3). The relatively narrow stalls, parallel side balconies and reflecting balcony soffits are characteristics of the former, the stepped seating areas and resultant additional reflecting wall surfaces of the latter. All seats are within the main acoustic volume.

Side circulation is within the hall but behind panelling, limiting the overall width of the hall acoustically. Adjustable reflectors are installed at the top level to provide early reflections to the gallery seating.

An array of reflectors is provided above the platform and choir seating to provide early 'ensemble' reflections between performers. To avoid visual obstruction of the magnificent Marcussen organ, these are constructed of curved glass (convex as seen from below) and carry the concert platform lighting. They are adjustable for height in sections. Individual hoists would have been preferable but were not affordable.

The bottom chord of the roof structure consists of steel tie rods and cast nodes, exposed within the acoustic volume. These were tested with high sound level impulses during construction to ensure no resonance and subsequent re-radiation of discrete frequencies of sound. The top chord is a concrete encased plate girder which supports faceted precast concrete panels. The panels provide sound diffusion, sound insulation and a visual soffit.

The window of the sound control room pivots upwards and the lower wall then slides forward, with the mixing desk to allow the sound technician to listen within the acoustic of the auditorium.

The seats were specially designed for this auditorium; an iterative testing and design adjustment procedure was carried out to ensure that the final design was within the upper and lower sound absorption coefficient limits set. The hall surfaces are mainly sound reflective at all frequencies: concrete, dense concrete block, veneered timber backed with MDF and stone. The floors are timber embedded onto concrete, the balcony fronts an average of 30mm glass reinforced gypsum.

Table 1 lists key design criteria, together with the achieved values.

Parameter	Target	Achieved
Mid-frequency RT	2.0s	2.05s
Mid-frequency EDT as %RT	90% - 100%	85% - 103%
Low frequency RT (125Hz)	≤2.5s	2.6s
Clarity Index, C_{80}	-1dB ±1.5dB	Average 1.1dB, 1.9dB range
Range in Loudness Index, L_T	5dB	5.4dB
Volume/seat	10m³	10.4m³
Furthest seat to platform	40m	37.4m
Building services noise limit	PNC15	PNC15

TABLE 1: Key Acoustic Parameters
All occupied, average of 500Hz and 1kHz octave bands, except as indicated

Evaluation and Testing

The design was developed using:

- 1:100 and 1:50 scale half models for analysis of first and second order early reflections using laser sources and mirrored surfaces
- a 1:50 scale acoustic model, using spark sources and MIDAS impulse analysis software
- an ODEON hybrid image source/ray trace acoustic simulation software model, with 500 modelled reflective surfaces.

The acoustic testing programme encompassed:

- impulse testing, again using MIDAS software and initial listening tests with individual performers and CD sources
- acoustic test rehearsals with the BBC Philharmonic (no audience) and the Manchester Camerata (around 350 audience)
- acoustic test concert with the Hallé Orchestra and Chorus and 70% audience occupancy.

The tubes associated with the individual underseat air supply units, which theoretically could act as Helmholtz resonators in the 200Hz frequency range, had no measurable effect upon the reverberation time as measured in ⅓ octave bands, nor any audible effect upon the sound field.

Following the acoustic test concert a number of minor adjustments were made to the hall. These included the inclusion of more high frequency sound diffusing elements on plane surfaces and the removal of core panels from most of the side reflector composite panels, to increase the absorption within the 125Hz octave band. These changes resulted in a noticeable improvement in aspects of the acoustic.

After one season of performances, the Bridgewater Hall has been judged to have a very good sound overall, with high clarity, appropriate loudness and a very wide dynamic range. Whilst designed primarily for symphonic orchestras and the organ, the auditorium has a good acoustic for small-scale and solo works. In marked contrast to most UK halls, the bass response is strong. Impulse analysis has indicated that the hall might benefit from further high frequency sound diffusion.

Airborne Sound Insulation

The Bridgewater Hall is close to the city centre of Manchester. It has busy urban roads to two elevations and is close to the Metrolink light rail system (Figure 4). The lower levels of the auditorium are surrounded by ancillary accommodation. The upper level walls are twin concrete and concrete block cavity constructions with stone and aluminium rain screen cladding. There is a double roof construction, with the lower layer comprising 200mm concrete slabs, a deep roof void (height 1.5m to 2.5m) and an outer mass layer of lightweight precast concrete planks (80kg/m^2) with a metal roof covering. The roof void incorporates an enclosure for the lighting bridge, which has a sealed concrete floor. This descends out of the lower roof slab when required for light entertainment events.

A criterion of L_{10} ≤PNC15 - 5dB was set (plus L_{max} ≤PNC20 for the specific case of occasional helicopter low-level overflights). External noise is inaudible within the auditorium.

Radiation of groundborne noise from the Metrolink light rail system was a major concern. As the railway was incomplete during the design phase a hydraulic shaker was used to provide dynamic force input along the track alignment. Vibration was then measured across the site in boreholes. It was determined that the entire building (approximate mass 25,000 tonnes) should be isolated, thus avoiding the extensive isolation detailing which is necessary when part of a building is isolated (Reference 1).

The circular in-ground columns are sleeved with a compressible foam to reduce vibration coupling to the ground. At the heads of the columns helical steel springs with a natural frequency in the 3Hz to 5Hz range provide the structural isolation. These are located within an isolation undercroft. 280 pre-compressed springs are installed. The isolation also includes resilient breaks in all services, stairwells and around the building perimeter, such that there is no rigid point of attachment between the building and the ground.

The vibration isolation is totally successful; the trains are inaudible within the auditorium. The analysis and system design has been described in more detail by Anderson (Reference 2).

Services Noise Control

The approach to achieving PNC15 - in effect complete inaudibility of services noise - was conventional, but there are points worth noting:

- the main plant (auditorium air handling units, chillers, pumps, boilers) is located in a separate plant tower, not isolated from the ground. All service connections between the plant tower and the auditorium include a flexible connection or break

- the auditorium air extract ducts run externally between the plant tower and the main building. Circular in section, with separate acoustic and architectural cladding, they incorporate complex vibration isolation, building movement and airborne sound insulation detailing

- the underseat air supply units operate at very low flow-rates such that the tonality which occurs at higher flow velocities is inaudible
- considerable attention was paid to control of acoustic noise from the auditorium lighting. This included testing and subsequent modification of the decorative lighting (which consists of several hundred miniature low voltage lamps on current-conducting wires), vibration isolation of the controllers for these lamps, located within the roof void and testing of a number of concert lighting luminaire and dimmer combinations, with inductive circuits incorporated to increase the dimmer rise times.

3 THE DESIGN TEAM

Acoustic consultant:	Arup Acoustics
Architect:	Renton Howard Wood Levin
Building engineer:	Ove Arup & Partners
Theatre consultant:	Techplan
Main contractor:	Laing North West

4 REFERENCES

[1] RD GREENWOOD AND R COWELL (1992), International Convention Centre, Birmingham: Structures and railway vibration isolation, Proc Institute Civ Engrs Structs & Bldgs, 24 Aug, pp 253-262

[2] D ANDERSON (1996), Manchester Concert Hall: Vibration Isolation, Proc Inter-Noise 96, pp 1561-1564

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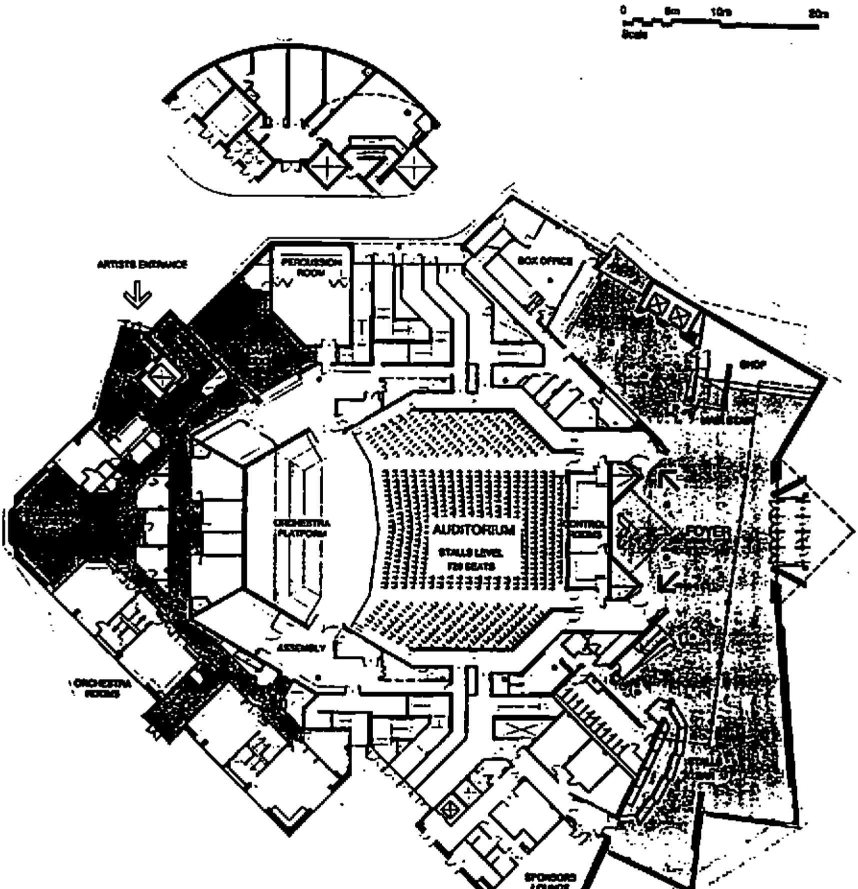

FIGURE 1: Plan at Stalls Level

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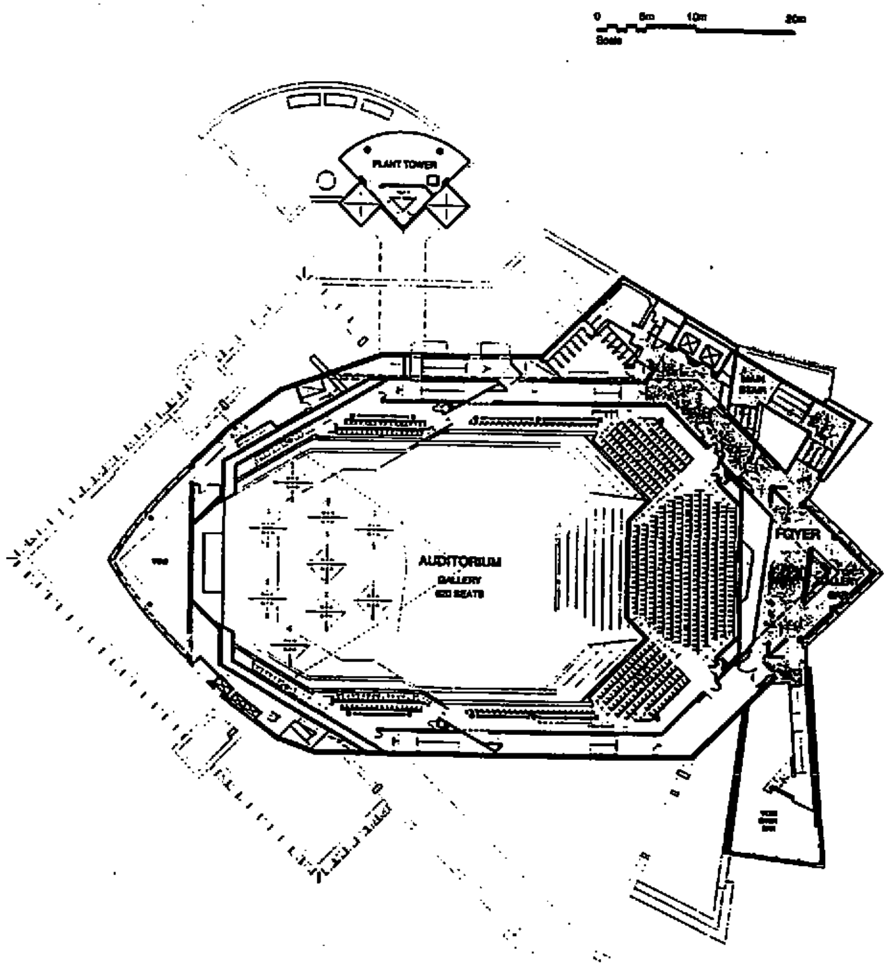

FIGURE 2: Plan at Gallery Level

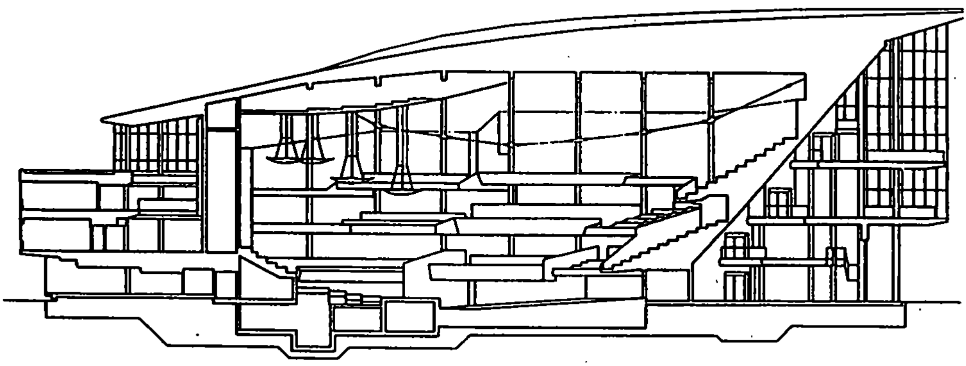

FIGURE 3: Long section through Auditorium

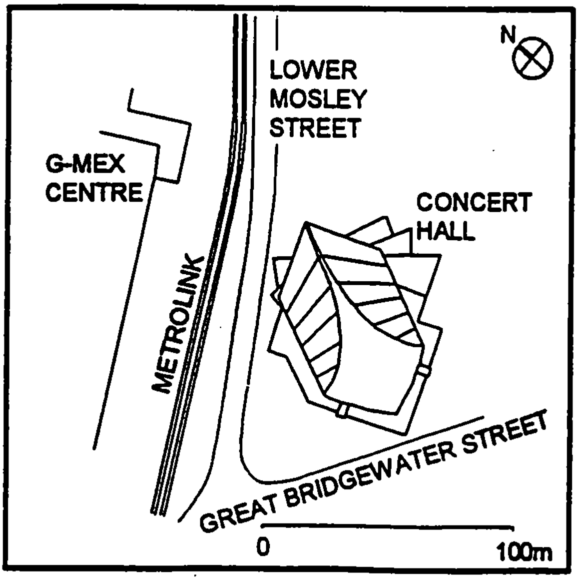

FIGURE 4: Site plan showing proximity of Metrolink