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THE ACOUSTIC DESIGN OF THE ANVIL CONCERT HALL, BASINGSTOKE

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1 INTRODUCTION

The Anvil Concert Hall opened in the centre of Basingstoke in the Spring of 1994 following a 2½ year programme from scheme design to practical completion. The Client was Basingstoke and Deane Borough Council. Architects were RHWL, leading a Design Team with Whitby and Bird as structural and services engineers, Techplan International (technical systems), Lighting Design Partnership and Bucknall Austin (cost consultants). Arup Acoustics were responsible for the acoustic design.

This paper describes the principal features of the acoustic design of the Concert Hall and initial measurement results.

2 THE BRIEF

The Client's Brief was for an auditorium to seat close to 1400 people, its primary use being for orchestral concerts, but with good capability for other uses. RHWL developed the Brief with the Client which eventually led to seven formats:

• Concert Format	1393 seats
• Proscenium Format	1063 seats
• Cinema Format	832 seats
• Arena Format	1399 seats
• Platform Format	1036 seats
• Pop and Rock Music Format	1400 total

A flat floor format is also possible. Of these, the Concert Format requires a very different acoustic and is the most demanding.

At various stages in the design, Arup Acoustics placed substantial emphasis on the importance of protecting the requirements for orchestral concerts. This included a need for an understanding by the management of the importance of removing unnecessary fittings, components and hangings for orchestral concert use.

The budget was less than £10M and was to include extensive support accommodation and an additional small hall (The Forge) for 100 - 130 (150 standing for a reception).

3 PLANNING

The site is noisy. Churchill Road to the south is a busy dual carriageway (Refer to Figure 1). Alencon Link carries local traffic to the North West and Basingstoke British Rail station is 120m to the North. An exit ramp from the shopping centre car park forms the north boundary of the site.

Early site measurements of groundborne vibration from the railway indicated that it was possible to construct the Concert Hall without the need for elaborate measures to isolate ground-borne noise.

In the planning of the building, the Concert Hall was separated from the Small Hall and support accommodation was wrapped around it providing a 'buffer' zone. Where this could not be achieved at high level, heavier double constructions were used. Double skin dense block walling without ties (or with resilient ties locally, as necessary) was used for upper wall construction. The roof is double skin with double-T precast concrete planks forming the ceiling of the Concert Hall (the contiguous thickness of the lower skin is 125mm ie ignoring ribs). The upper roof (100mm lightweight concrete planks and weathering) is spaced off the precast deck by 150mm, on steels clamped down through elastomeric strips.

All access to the auditorium is, of course, lobbied and external glazing local to the outside of lobbies was upgraded for improved sound insulation.

Simple provision was made in the construction of the raked seating to include constrained layer damping to reduce response to residual railway vibration.

Heating and cooling plant, dimmers, pumps, lifts and lift motor rooms are located away from the auditorium. Air handling plant is positioned in a plant tower, separated from the stage end of the Concert Hall by one room depth of accommodation and a structural isolation joint. Toilets are located below the rear seating rake but are built as a separate structure.

Planning of the air supply and extract systems for the hall is as follows. Air is fed through primary attenuators in the plant tower, over the isolation joint, into builder's work plena at a half level along the flank walls of the choir. Secondary attenuation is set within the plena (also providing attenuation of any external noise breaking in via the structural separation joint). The builder's work enclosure continues along the side walls reducing in size as the supply air quantity reduces. Finally, air is supplied into the Hall through 'Jetflo' diffusers backed by short lengths of lined ductwork suspended free in the supply airway. A small plenum over the choir serves the central choir area again via secondary attenuation, but in this case via a simple air supply slot.

Subdivision of the builder's work duct by sheet metal dividers allows zoning of the supply air.

4 THE CONCERT HALL ACOUSTIC

4.1 Geometry

A number of early design decisions were taken to produce a Concert Hall acoustic of the highest quality.

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First, the plan form of the hall (see Figure 2) was developed to combine reverse fan and shoebox form into a stretched octagonal form. Second, the target volume was set at $10m^3$ per seat ie $14000m^3$, which was achieved - (see Figure 3). The geometry of the side and rear side walls was developed to provide early lateral reflections to the audience. (see Figure 4).

More difficult was the scope to flatten the rake of the seating to reduce the sound absorption in the upper volume. This was constrained by the necessary rake of 288 bleacher seats forming much of the stalls (and necessary to permit other formats). It is likely that the rake is partly responsible for the significant change in response between the full and empty conditions, referred to later.

At an early stage, considerable uncertainty arose over the appropriate distribution of height over the plan. Apart from limited areas at the rear of the hall, all reflections from the ceiling are late. Although it was known that those reflections should be relatively diffuse, there seemed to be little guidance on the positioning of room volume for maximum advantage. To obtain an indication, a simple 1:50 foamcard model of the auditorium was made without a roof. Alternative roof profiles were then added concentrating volume over the platform , over the rear of the hall and over the front stalls. A flat roof was also tested. Using a spark source, simple checks on RT, clarity, loudness and impulse responses in the model influenced the design towards a geometry which placed most volume over the front stalls.

The steep rake along the longitudinal axis and the preference for volume over the stalls tended to restrict height at the back (as is often the case). The roof was lifted slightly at the back to ensure adequate space for a diffuse sound field to develop there.

The principal dimensions of the hall are:

Overall width:	31m
Stalls width:	19m
Furthest seat to platform:	28.5m
Overall length:	45m
Height immediately in front of the stage:	18m
Platform area:	$154m^2$ (17.5m wide at front, 11m deep)

Builder's work ducts were used to distribute air along the walls at half height level. These ducts running along the choir flank and side walls and the angles of the choir flank rear walls together provide a good pattern of early reflections to the choir and parts of the orchestra. Early lateral reflections are provided in the stalls by fibrous plaster panels forming the side stalls balcony fronts tilted forward at the top at an angle of 15° from the vertical. Similar panels face the side wall duct, just above the side stalls, set at an angle of 22° from the vertical. The soffit of the duct and side walls provide 'cue-ball' reflections to support the early reflections from these panels.

To provide further early reflections to seats at the rear of the auditorium, larger reflector panels, following the plan form of the reverse fan, were constructed again in fibrous plaster. Studies used laser light and mirror card in architectural half models. A simplified ODEON computer model informed the hall geometry and panel angles.

The rear wall is for the most part formed in convex plaster panels combined with modelled ports for projection. A small area overhanging the control room windows has a soffit tilted to reflect sound from the glass and soffit immediately onto rear seats.

The platform surround includes tilted reflector panels forming the front of the choir. The intended multiple use of the hall resulted in pressure to add flying space above the platform. There was a danger that an upstand above the platform (potentially full of stored material) might adversely effect the Concert Hall acoustic due to extra absorption. To avoid a substantial step up into such a flying space, a suspended box formed in steelwork and multiple layers of fire rated board was formed over the front of the platform. This provided for storage of the material which forms a proscenium when required and provided reflections back into the audience areas.

4.2 Overhead Orchestral Reflector
Checks on the pattern of reflections back to performers from the choir rear walls and overhanging soffits indicated that, for the central part of the orchestra, these would arrive slightly late (after 70ms). An overhead orchestral reflector was considered necessary to provide for 'ensemble' to a better standard.

The additional earlier reflections were not needed over the full orchestral area. Because of this and a wish to avoid interference with 'Jetflo' air supply to the platform, it was decided to concentrate the reflector into the centre. Size and geometry were also influenced by the need to allow sound to be redirected to the orchestra and to pass into the upper volume [1]. A further influence was the ability to achieve the required mid and high frequency reflections from a relatively lightweight material, allowing ease of handling. The final construction is fan shaped on plan (in response to the form of the platform), with slight convex curvature on the underside. The reflector is formed in GRP, the panel surface weight being $7kg/m^2$. It contains some of the orchestral lighting.

4.3 Diffusion
The approach to diffusion was to use a very limited amount on panels providing early reflections and heavier diffusion on surfaces providing late reflection. Excessive areas of diffusion, which might disturb the listener's sense of aural perspective, were avoided.

For panels providing early reflections, it is helpful to provide a little high frequency diffusion to prevent image shifting or 'harsh' high frequency reflection. This can be achieved by surface modelling or by convex curvature [2]. The latter was considered less 'busy' and better suited to the interior. A radius of 8m was therefore applied to the reflector panels. In theory the radius should vary with distance from the stage. The fixed curvature was chosen to provide a compromise, allowing for consistency of appearance.

Most of the lower walls provide early reflections. Where 'cue-ball' reflections occur under overhangs, it was considered unnecessary to add diffusion, as there would be at least two reflections in sequence. Upper walls, which are essentially formed by the sides of the air supply and extract ducts, could be relatively plain as these are redirecting sound on to the diffusing ceiling above.

Trusses and perforated walkways crossing the upper volume and a modelled roof deck provide substantial diffusion at high level. The ceiling was formed using double T precast concrete planks cast with sides of the T shortened. By careful arrangement of these narrowed planks, it was possible to obtain a relatively random pattern of one way ribs, of 300mm depth, providing effective diffusion without colouration.

Lighting bridges were perforated to reduce their screening of propagation of the sound. At the same time, care has to be taken to limit hole sizes in walkway flooring for safety reasons.

4.4 Sound Absorption

A major objective of the design and a most important feature of the resulting acoustic was a significant rise in the bass response of the auditorium. Great care was taken to maintain a substantial surface weight and stiffness at the room boundaries. Apart from plastered blockwork, boundary construction was based on a surface weight exceeding 50kg/m² (30kg/m² for panels of small area). The flooring used 45mm board and timber laminated construction. Bleacher seat platforms were constructed with a surface weight exceeding 30kg/m².

A bass rise is less helpful when the hall is used for other purposes. At one stage in the design, it was proposed that banks of low cost Helmholtz resonators, set behind heavy doors, could be exposed when bass response needed to be reduced. Necessary economies during construction resulted in these being deleted. At the same time, space has been allocated for their later addition should this be considered necessary.

Seating of course provides the dominant mid and high frequency sound absorption. From a range of potential seats appropriate to a tight budget, seats from *Auditoria Services Ltd* were selected. Four types of audience seating were necessary - loose seats for the front of the stalls, seats to fold on the bleacher system, standard seats and high-backed seats for the rear of the hall.

Upholstery on all seats was the same, namely 70mm open cell foam on the squab and 50mm on the back on a plywood base. An additional 10mm of foam was attached to the underside of the squab and backside of the back. All the foam was covered with a woven cloth of low flow resistance.

Early tests were carried out on the standard seats. As the design was developed, a further final set of tests was carried out using a mix of seats representative of the mix in the hall. Tests were made according to ISO 354: 1985 (now BS EN 20354) using barriers surrounding the sample according to Reference [3].

The final test data is set out in Table 1.

After this test, as the 4kHz absorption was higher than specified, a minor change was made to the upholstery to the upper part of the high backed seats by introduction of a tightly woven fabric to reduce absorption.

4.5 Facilities for Other Formats Affecting Acoustics

A change from Concert to Proscenium or Platform formats involves the emergence of a 'goalpost' frame from the floor of the platform. An opaque fire rated fabric is then rolled down from high level storage to form the proscenium. To complete this barrier two hinged panels move out from the side walls and fill the gaps at the sides. The effect on acoustic response is to add a little absorption and to begin to divide the volume of the hall. This format will often include substantial hangings on the stage. (see Figure 5).

A projection screen for cinema and conference use is also stored in the floor of the platform. Masking drapes add to the absorption in the hall.

When a flat floor format is used, the removal of the bleacher and loose seating leaves the room potentially very 'live' and response is very much affected by the nature of the event eg exhibitions, trade shows, banquets.

For the Rock and Pop format, again the bleacher and loose seating is out, a backcloth behind the stage introduces useful absorption but shields the choir seating.

The Arena format is not very different from the Concert format in terms of absorption by seating but the change of source position required attention, particularly in the configuration of the sound reinforcement system.

4.6 Drapes

All of the non-concert conditions were potentially too 'live'. Consequently, the reduction of reverberation by means of banners or drapes was proposed early in the design. Initial estimates of quantity suggested that up to 600m² of relatively efficient banner or drape material should ideally be introduced to reduce the reverberation time for other uses of the hall. Arrangements were made in the planning to provide blockwork storage boxes with solid doors to remove the absorption fully from the room volume for the Concert Format.

Again, restraints from the budget limited choice of material. The most cost effective provision was the use of conventional theatrical drapes in wool serge. A heavy material (450gm/m²) was selected. The material was bunched using twice the material which would cover the area if stretched flat (ie 200% drape). Laboratory tests were carried out to determine the performance of single and double layers of the material set over an airspace within a solid timber frame surround in a 200m³ reverberation chamber. Random incidence absorption coefficients are given in Table 2.

A check was also made on the scope to achieve significant low frequency absorption by a flax fibre drape stretched over a 250mm airspace. Results were unimpressive.

Following the test work, it became necessary to tighten the investment. Single drapes were therefore used (again 200% drape) over a mean 250mm airspace. The positioning of the drapes was influenced by preferences for wide distribution of positions for the material and to make more provision at high level. The majority of the material is set around the high level technical gallery. Some is placed on the lower side stall rear walls and in front of the reverse fan rear side wall. Two motorised runs of drapes also feed alongside high level catwalks bringing material into the centre of the upper volume. The material is then supplemented as necessary by hangings from bars over the platform. A total of 450m² of banner material is normally available. For orchestral concert use no drapes are present.

4.7 Sound Reinforcement

The design of the sound reinforcement was carried out by Techplan International to a very limited budget. This permitted only a main cluster of directional horns + direct-radiating bass loudspeakers over the front of the stage with a second group of horns for fill towards the rear of the auditorium + scope to add mobile components to serve the choir and platform areas for other formats. It is important to note that the emphasis on concert use produces hard wall surfaces. This has meant that great care has been necessary in operation of the system to obtain the necessary coverage without exciting long path reflections from hard wall surfaces.

5 RESULTS

Measurements of the acoustic response of the room have been carried out during final stages of construction and commissioning. The wide variety of potential arrangements and contents means that it has not been practical yet to gather data for all circumstances. Data referred to here relates primarily to the Concert Hall with some indicative reverberation time figures for the Proscenium and Arena formats.

5.1 Background Noise

Tests carried out when the airflow systems for the Concert Hall had been commissioned for airflow provided results usefully better than predicted. Against a target maximum of PNC20, PNC17 (NR15) was achieved with maximum airflow. Reductions in airflow or zoning to feed air into part of the auditorium allows lower noise levels, useful for professional recordings.

External noise was not found to have any significant effect on these levels. Residual railway noise can be detected by a very discriminating listener in the quietest of moments, but is not significant.

Despite careful control over operational noise from the lighting, including testing and specification for dimmers, noise from low voltage lighting was noted initially, arising from thermal contraction after dimming. Adjustments have been made to lamp components to deal with this. Management control on switching off hoist drive system panels (which contain small cooling fans) is also important for the Concert format.

5.2 Room Response

Table 3 sets out measured RT, EDT and Clarity Index values at selected seats in the auditorium in the Concert condition compared with target values. Overall, the response is very good. There are some aspects of the results which warrant further comment.

The extent of change of RT with occupancy was more than expected, and more than indicated by the laboratory tests on seating. This may be explained in part by the use of tip up seating on a relatively steep rake (and there is a substantial area of this in the Anvil) exposing more floor in the unoccupied conditions than for shallower rakes.

A second impression from listening in the hall, is that for the fully occupied condition the clarity is excellent, yet very strong early reflection, in places, leads to reduced perception of the reverberance. The EDT is shorter than target.

Loudness is substantial. For the most powerful events approaching the desirable limit. Further study of this and of the balance between early lateral energy and late reverberant energy is proposed.

Table 3 also includes examples of RT for the Proscenium and Flat Floor conditions.

6 REPUTATION

The overall reaction from performers, audience and management has been very favourable and to date, the hall has been earning a reputation for acoustics of international stature. The concerts have covered a wide range of repertoire and sizes of performing groups. There are now plans for its use as a recording venue. The use of the auditorium in other formats has been generally successful acoustically, although there has been a substantial learning process for the hall management, bearing in mind the wide range of potential offered by the facilities. The continued success of the acoustic design is now very much dependent on its proper management and a continuation of the high standards of performers booked for the hall.

7 REFERENCES

[1] J H RINDEL, 'Acoustic Design of Reflectors in Auditoria'. Proc IOA 14 Pt 2 p119 (1992)

[2] J H RINDEL, 'Attenuation of Sound Reflections from Curved Surfaces'. Proc 24th Conference on Architectural Acoustics, Strbske Pleso - The High Tatras CSSR 1985

[3] W J DAVIES, R J ORLOWSKI & Y W LAM, 'Measuring auditorium seat absorption', Journal of the Acoustical Society of America, 96 No 2 Pt 1 p879 - 888 (1994)

Condition	Octave Band Centre Frequency, Hz						
	63	125	250	500	1k	2k	4k
Unoccupied	(0.11)	0.42	0.56	0.69	0.78	0.84	0.86
Occupied	(0.18)	0.49	0.68	0.76	0.81	0.87	0.89

TABLE 1: Random incidence absorption coefficient data for auditorium seating (Note: Minor adjustments made to seats after testing)

Drape Arrangement	Octave Band Centre Frequency, Hz						
	63	125	250	500	1k	2k	4k
A. Single bunched drape over mean 100mm airspace	(0.06)	0.13	0.40	0.70	0.74	0.88	0.89
B. Single bunched drape over mean 250mm airspace	(0.07)	0.22	0.64	0.80	0.80	0.90	0.92
C. A combined with B to form double bunched drape	(0.08)	0.39	0.75	0.93	(1.0)	(1.0)	(1.0)

TABLE 2: Random incidence absorption coefficient for drapes in laboratory tests ($10m^2$ samples)

Parameter	Condition	Octave Band Centre Frequency, Hz							Target (Fully occupied)
		63	125	250	500	1k	2k	4k	
EDT(s)	Concert - Occupied Concert - unoccupied	2.7 3.1	1.9 2.3	1.8 2.15	1.6 2.2	1.55 2.05	1.5 2.1	1.2 (1.3)	RT±10%
RT(s)	Concert - occupied Concert - unoccupied	2.7 3.1	2.2 2.5	1.95 2.25	1.85 2.3	1.75 2.3	1.65 2.15	1.4 1.6	$RT_{500,1k}$ 1.8 - 2.0s
	Proscenium - unoccupied with drapes exposed	2.6	2.0	1.8	1.7	1.6	1.5	1.2	
	Flat floor - unoccupied with drapes exposed	2.9	2.5	2.5	2.5	2.4	2.2	1.7	
Clarity (C_{80})	Concert occupied				-1dB to +1dB				~0dB

TABLE 3: Measured Data

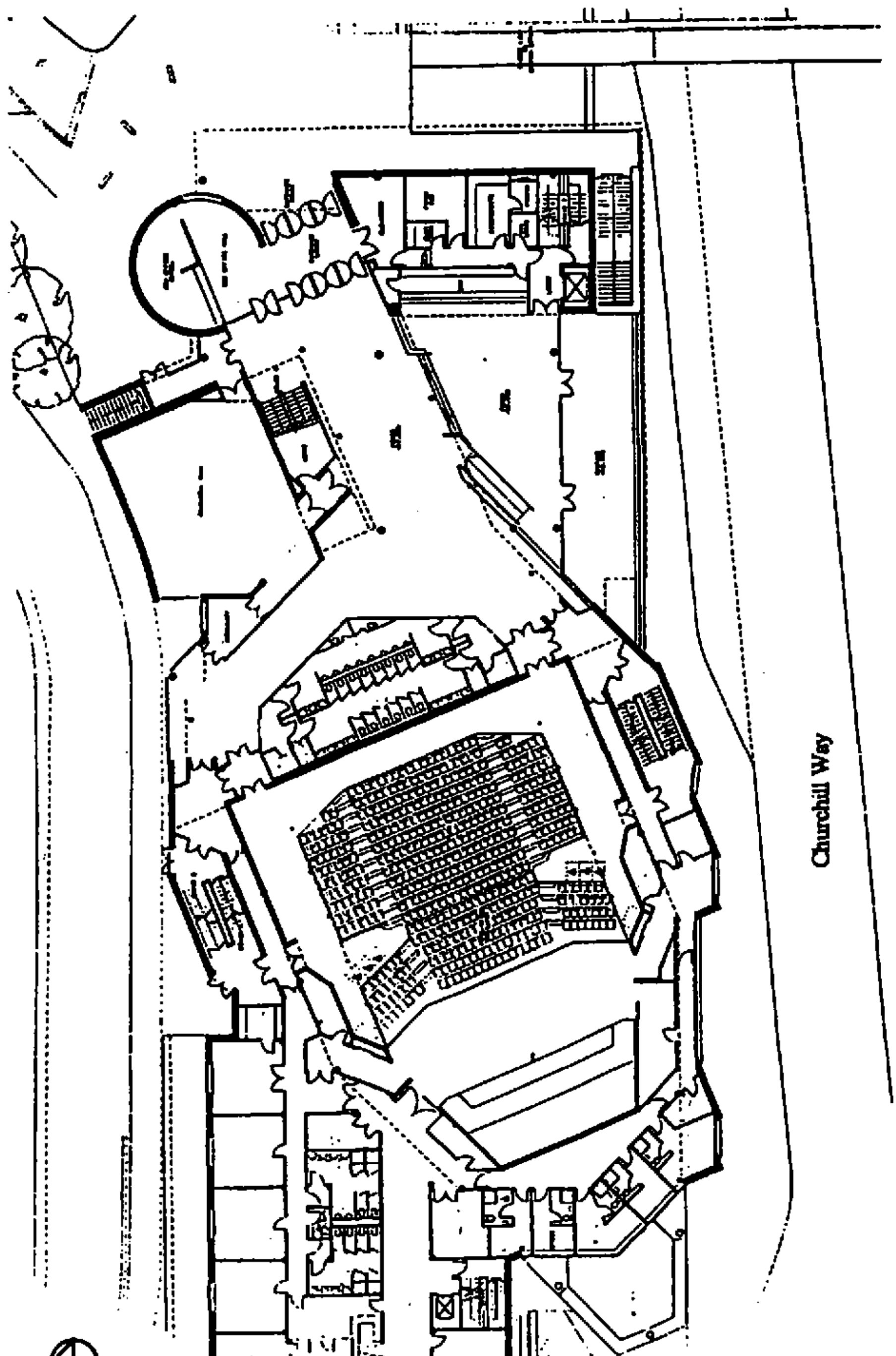
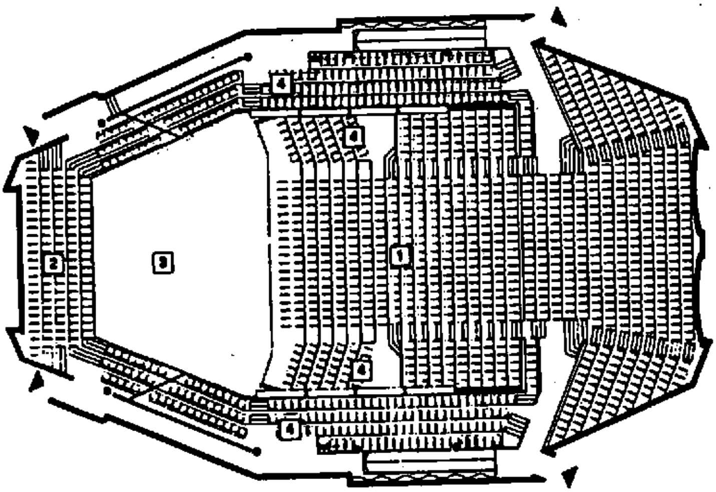


Figure 1 : Building Plan at Stalls Level



1393 seats total

[1] 1234 seats [2] 159 choir seats [3] 100 orchestra (approx.)

[4] 12 wheelchair spaces, 6 on each level

Figure 2 : Plan Concert Format

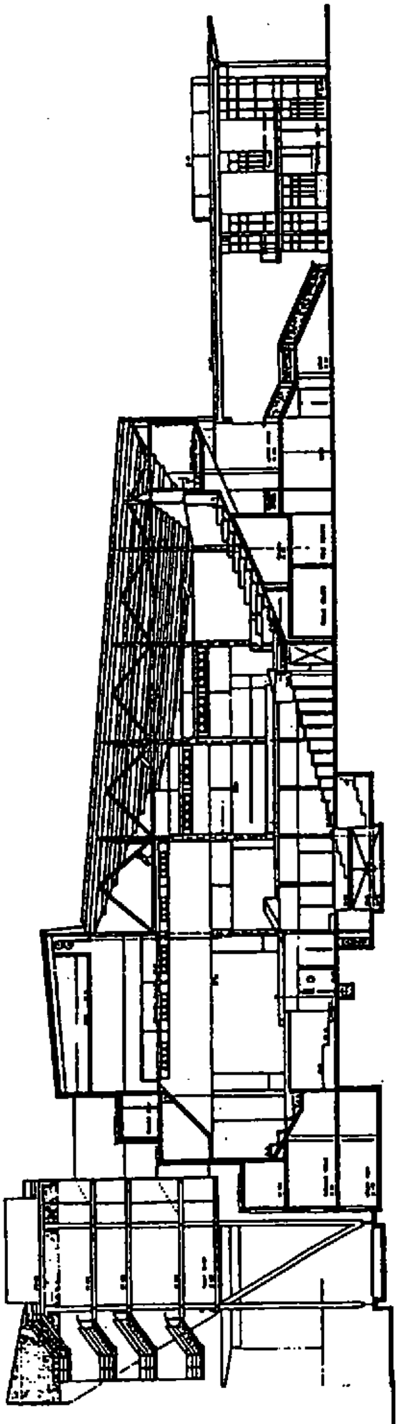


Figure 3 : Long Section Concert Format

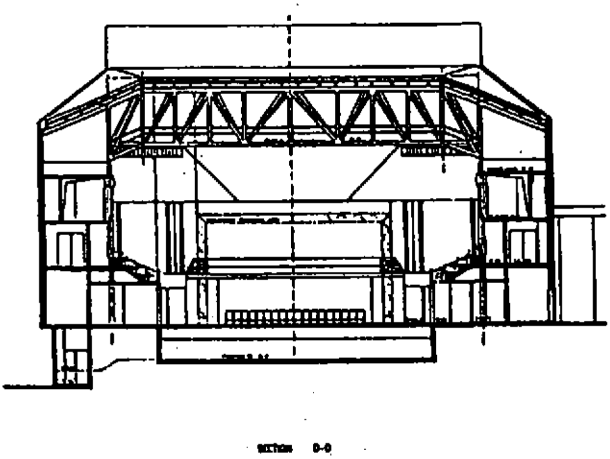
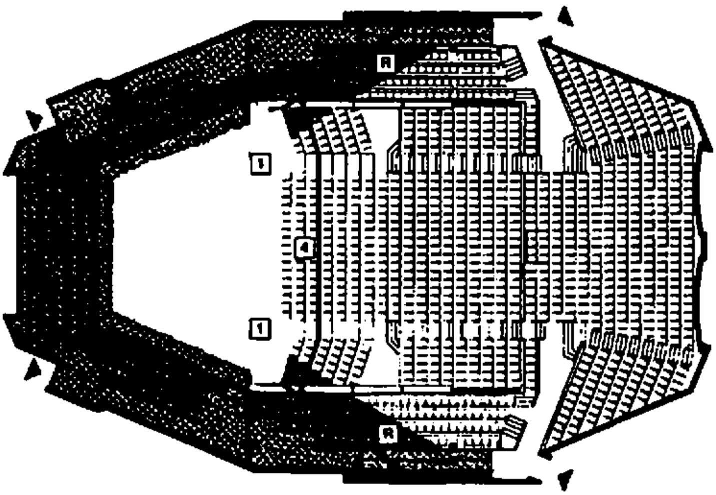


Figure 4: Cross Section



1060 seats (inc. 36 restricted view – R) without orchestra pit
992 seats (inc. 32 restricted view – R) with orchestra pit
1 Proscenium arch and walls in position 4 Orchestra pit (optional)

Figure 5 : Plan Proscenium Format