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THE IMAX CINEMA, WATERLOO, LONDON - AN ACOUSTIC CHALLENGE !

P Henson Bickerdike Allen Partners
JG Charles Bickerdike Allen Partners

1. INTRODUCTION

The IMAX Cinema, Waterloo is located at the southern end of Waterloo Bridge, in the centre of a roundabout. Owned by the British Film Institute (BFI), it forms part of their expanding South Bank development. The IMAX Cinema opened to the public in May 1999. It boasts the "largest cinema screen in Europe", around 20 metres in height. An IMAX cinema specialises in large 2D and 3D format films. The Waterloo IMAX also houses 35 and 70mm projection facilities.

From a commercial viewpoint, the BFI consider this location ideal for one of their flagship buildings. In contrast, acoustically, it would be hard to find a more challenging and less ideal site for a cinema. Located in the centre of one of London's busiest roundabouts, it lies less than 40 metres from an elevated railway carrying British Rail traffic over a series of steel bridges and brick viaducts. Below the site, only a few metres below ground level, there are two tunnels carrying London Underground's Waterloo and City Line trains. Aircraft bound for Heathrow and helicopters overfly the site.

The building is cylindrical in shape, with restaurant, ticketing and public areas at ground floor level. The 500 seat auditorium makes up much of the remainder of the building from 1st floor to 6th floor. A glass gallery surrounds much of the building which is steel framed with concrete floors and mainly plasterboard walls. Figures 1 and 2 show a cross section through the building in plan and section respectively.

2. FEASIBILITY AND DESIGN CRITERIA

The basic acoustic design aims, set by the IMAX Corporation for the auditorium, are:-

External Noise	to be inaudible within the auditorium
Building Services Noise -	not to exceed NC 25 with all systems operating, and to be free of tonal or impulsive components.
Cinema Acoustic -	reverberation time to not exceed 0.7 seconds, with a 25% uplift allowable at low frequencies.

Given the lightweight nature of the proposed construction, it was considered noise (L_{10}) from road and rail traffic could be controlled to around NC 25, thus peak levels may therefore just be audible at times against a quiet background but would most likely go unnoticed by the audience.

To convince the client, BFI, that this would be acceptable, a simulation was undertaken in the small IMAX cinema in the National Museum of Film & Photography in Bradford. The simulation involved replaying within the cinema the sounds that might arise from Underground trains below the proposed site, during film shows and between films. This confirmed the criterion of NC 25 as appropriate.

3. VIBRATION FROM UNDERGROUND TRAINS

A major task was to control the level of noise in the cinema as a result of vibrations set up in the ground from Underground trains passing beneath the site. It was determined that acceleration levels in the cinema building needed to be 20 dB less than those measured in the ground in the vicinity of the tunnels. Various methods of vibration control were considered including:-

i) control at source, such as treating the tracks in the Underground tunnels by replacing jointed track with welded track and/or using either base plate pads or a resilient layer beneath the track. This was found to be not practicable.
ii) double sleeving of piles. This was discounted in view of the relatively small reduction in vibration levels attainable and the cost and practicalities of piling much deeper.
iii) constructing trenches filled with sand, parallel to the tunnels. This was also discounted on the grounds of cost/practicality vs benefits.
iv) maintaining a 3 metre clearance between nearest piles and Underground tunnels together with an air gap between the building structure and local ground. This was implemented.
v) constructing the building on anti-vibration bearings. This was implemented using GERB pre-compressed steel springs, selected to operate with a system resonant frequency of 3.5 Hz.

The position chosen for the location of the anti-vibration bearings was beneath the first floor slab, on top of columns. The unisolated ground slab was built as a series of deep beams and shallow slabs over the tunnel zone to introduce an air gap beneath it. Polystyrene was used as a temporary formwork beneath narrow beams and later removed. For wider beams, a novel approach was required. Clayboard was used as temporary shuttering for these beams. This was later collapsed by wetting, thus forming a physical gap beneath the slab and local ground.

Above ground, various precautions were taken in the design process to minimise bridging across the bearings. These included:-

i) careful arrangement of building services to minimise the number of duct and pipe runs spanning the ground/first floor interface,
ii) stairs built in sections with a physical break provided at mid-landing level between ground and first floors,
iii) lift shafts broken by a soft joint at ground/first floor interface. The lift itself passed across this interface on guide rails attached to a steel cradle suspended from the first floor structure thereby ensuring no contact with the ground floor structure.
iv) the provision of a fire resistant soft joint at the head of internal masonry walls at ground floor level, at the underside of the isolated first floor slab.

A general picture of how vibration levels varied during the construction of the IMAX building is shown in Figure 3. It is interesting to note how vibration levels reduced over the construction period on the first floor slab, starting at around 60 dB re 10^{-5} ms^{-2} acceleration level (@ 31.5Hz) when the springs were in place but unreleased and reducing to around 42 dB on completion of the project.

4. INSULATION AGAINST EXTERNAL NOISE

Noise from overground trains and road traffic, such as produced by lorries and buses accelerating up the incline toward Waterloo bridge, is at times very high. A typical noise spectrum is set out in Figure 4 indicating road traffic levels incident on the outer wall of the IMAX building.

The lightweight nature of the cinema building is not ideal for controlling low frequency sounds generated by these types of sources. Maximum levels of up to 100 dB were measured on the site from some passing vehicles.

4.1 Auditorium Walls

The first line of defence against external noise is provided by the 12mm thick laminated glass wall formed by the Gallery which extends from 2nd floor to just below the roof of the IMAX building, beyond the 6th floor. The Gallery is around 3 metres in width. It is penetrated at high level by a series of 40No. Vent-axia type fans and by a similar number of slots in the floor to allow air circulation.

At 1st floor level, the auditorium wall is not protected from noise by the glazed gallery. At this level, dense 215mm blockwork has been used in conjunction with an independent plasterboard inner lining to achieve the required acoustic performance.

The main section of drum wall behind the screen has been designed to maximise its low frequency performance. The wall construction is shown in Figure 5.

4.2 Roof

The curved roof profile is formed by a lightweight metal lined on the underside by close boarded timber. The eaves of the roof are used for ventilation purposes. These form chambers which serve various plantrooms at 3rd and 6th floor levels. The walls of the chambers are studwork, double skinned with fire resistant boarding to control the acoustic conditions in the roof space.

The auditorium ceiling comprises a t&g timber boarding, with an M/F ceiling suspended beneath, comprising 2x12.5mm plasterboard layers. A mineral wool quilt is located inside the void. This void varies in depth from around 300 mm to 900 mm.

Figure 4 shows the variation in noise level around the building. For noise levels in the auditorium, a comparison is made between measured levels and the criterion of NC 25. Measured levels relate to when building services are operating and thus the results unfortunately do not reflect the full sound insulation capabilities of the building envelope. The results show however that the criterion has been achieved.

5. AUDITORIUM ACOUSTICS

Unlike in a conventional auditorium, where the natural acoustics of the space play a major role in the aural experience, the IMAX experience relies on the sound system to provide all colouration and reverberation. The IMAX requirements are for a space as acoustically "dead" as possible, but with a limiting maximum reverberation time of 0.7 seconds for a cinema the size of the one at Waterloo. Some uplift at low frequencies is permitted, Figure 6.

Additional requirements, although not quantified by numerical specification, are that there are to be no acoustically reflecting surfaces that could cause sound reflections to affect the sound experienced at the ear of the listener.

The auditorium has a volume of over 13000m^3. In view of the requirement to control the ingress of low frequency noise from passing cars and trains, it was desirable to use a material with very good low frequency absorption properties. Laboratory tests were undertaken to find an efficient material for treating the walls and ceiling of the auditorium. The final selection was a 150mm Melamine foam, manufactured by Noise Control Centre. This was found to have very good absorption properties at low frequencies when mounted solidly, around 0.9 at 125 Hz under laboratory conditions.

This material has been used on all walls, including that behind the screen. Partial areas of the ceiling have been treated with 100mm thick foam, around the edges. This is because a suspended structure has been provided in the auditorium at high level for lighting purposes and baffles of 100mm Melatech foam have been provided on the underside of this structure. An acoustically transparent woven cloth material, provided by Fabritrak, has been provided to those sections of foam visible to the audience.

Reverberation time measurements were conducted in the auditorium using the Sonics (IMAX) speakers behind the screen. The results of reverberation time measurements are shown in Figure 6 and compared against the specified maximum limits. Unlike in conventional auditorium design, where a target reverberation time is sought within upper and lower limits, the aim here was to obtain as low a reverberation time as possible.

6. BUILDING SERVICES

The auditorium is ventilated by supply air from beneath the audience seating rake. This raked structure consists of concrete treads and timber infill risers and is used as a supply air plenum. Diffusers are located beneath each seat. Air is extracted from the auditorium by grilles located in the ceiling. These grilles are connected to secondary attenuators to control the ingress of traffic noise from inside the roof void.

Conventional methods have been used to control noise from building services systems generally. These include the use of primary and secondary attenuators to systems serving the auditorium, duct lagging where some sections of duct pass beneath the auditorium seating, and vibration isolation of plant items, ducts and pipework.

Plantrooms are located on the 3rd floor and 6th floor, adjacent to the rear wall of the auditorium. The walls separating these spaces are twin framed, with two or three layers of plasterboard in places on each side and a mineral wool quilt in the void.

7. CONCLUSION

Despite an acoustically hostile site, and a lightweight building construction, noise levels from road and rail traffic have been controlled in the auditorium to the design target of NC 25. Reverberation time targets have also been achieved. The IMAX cinema is now open and operating successfully and it is heartening to experience, when entering the auditorium for the first time, how eerily quiet it seems considering the close proximity of the passing road traffic outside.

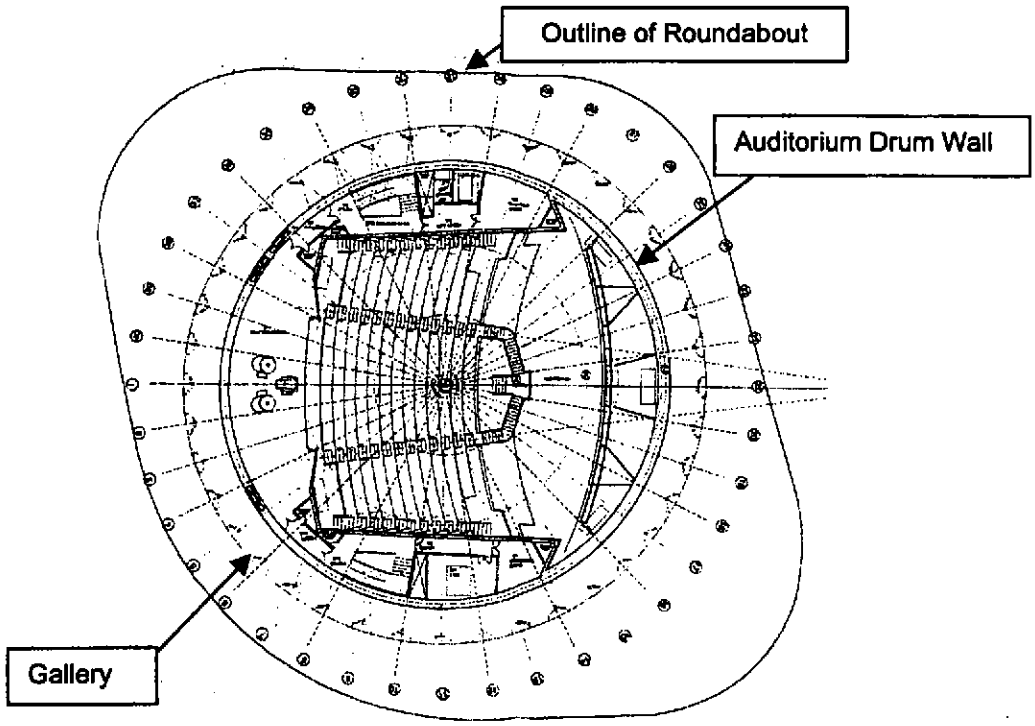

Figure 1 - Typical Auditorium Plan

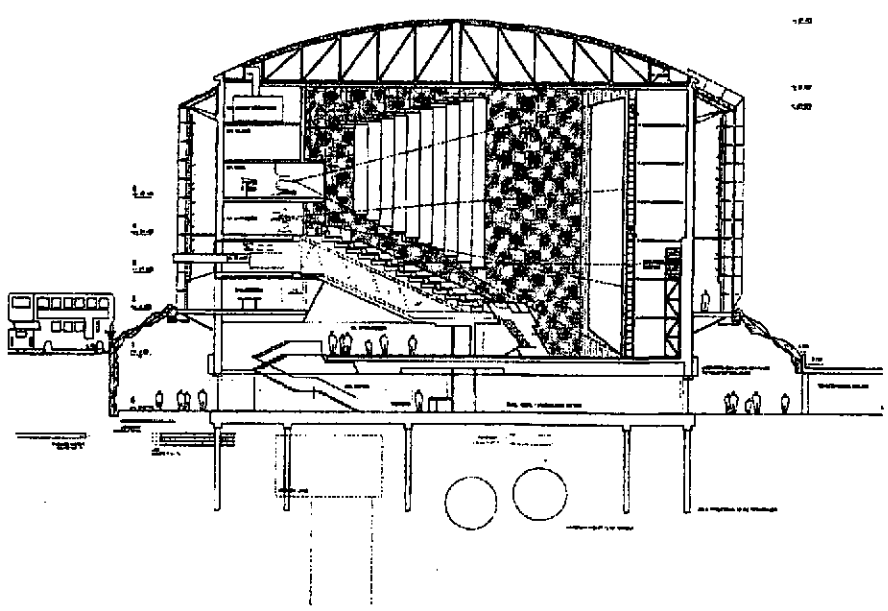

Figure 2 - Section through Auditorium

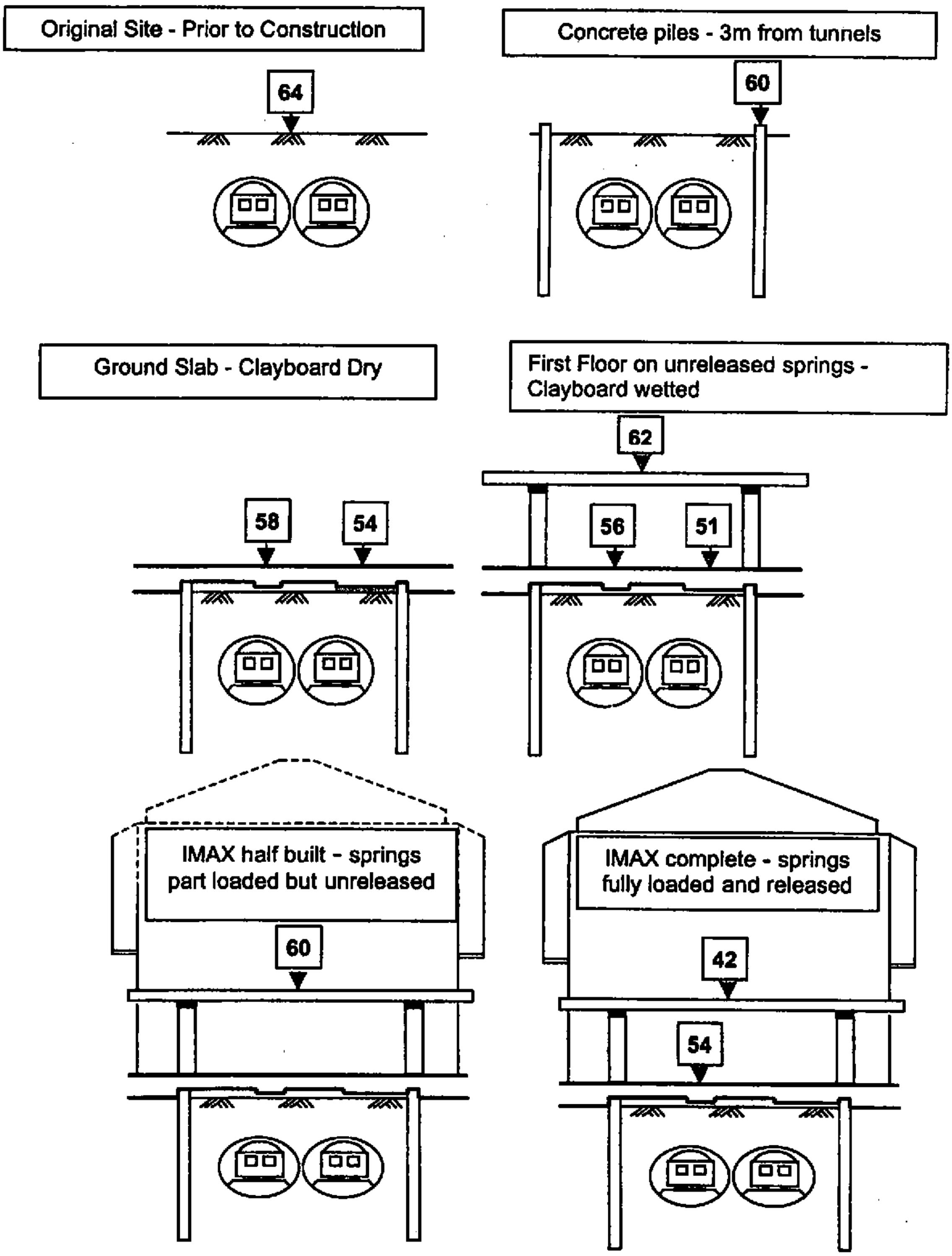

Figure 3 - Vibration from Underground Trains

Max. Acceleration Levels, dB re 10^{-5} ms^{-2}
at 31.5 Hz Octave Band

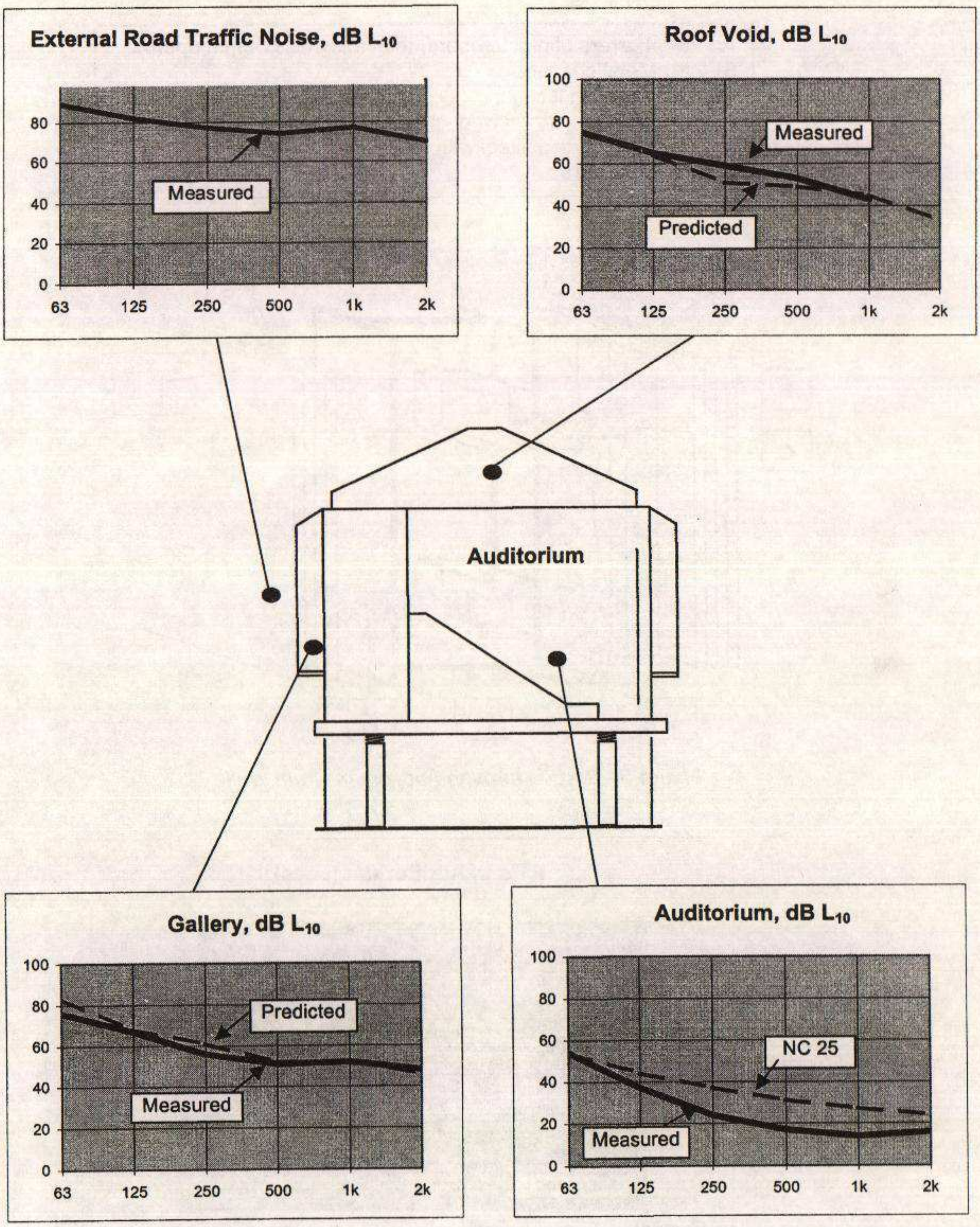

Figure 4 - Variation in Noise Level around IMAX Building

A	4 layers of plasterboard, total thickness 50mm approx.
B	Metal channel
C	Vibration isolator
D	100mm mineral wool quilt
E	Main vertical steel with intermediate cross steels
F	Metal strap

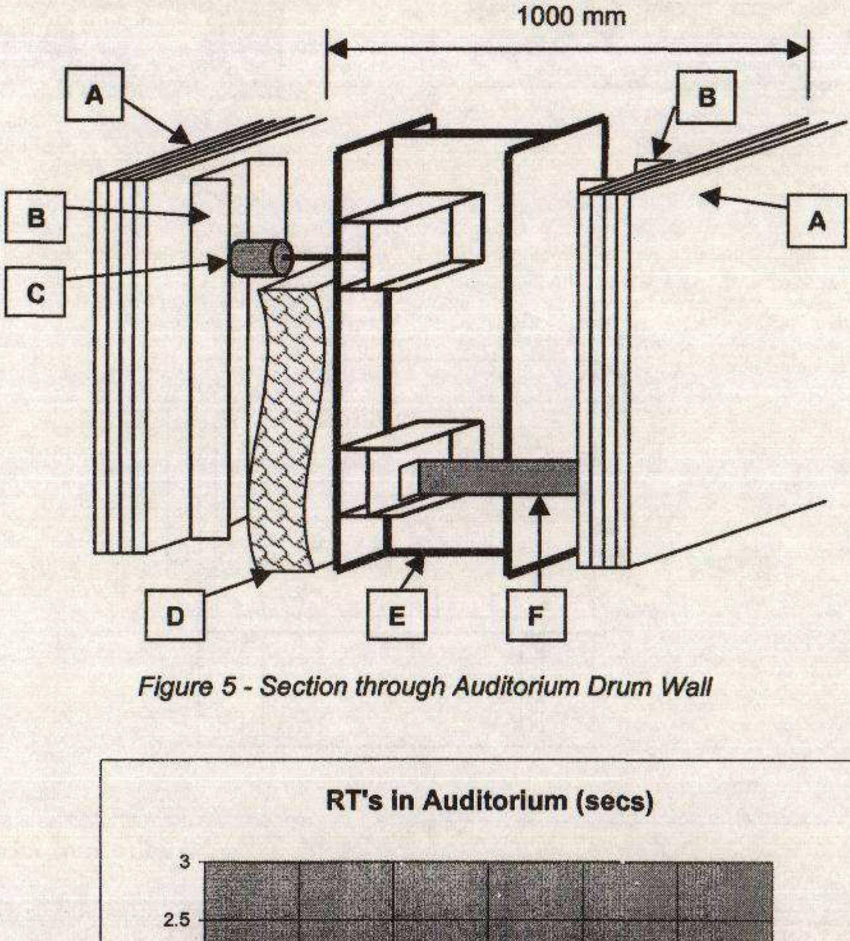

Figure 5 - Section through Auditorium Drum Wall

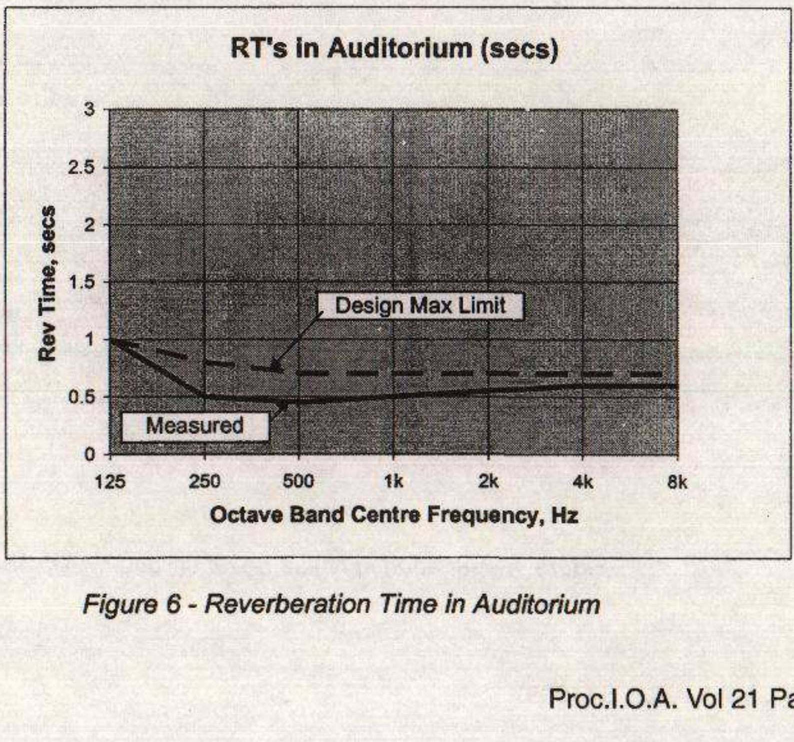

Figure 6 - Reverberation Time in Auditorium