AUDITORIUM ACOUSTIC DESIGN

HONG KONG ACADEMY FOR PERFORMING ARTS

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CONTENT

ACOUTICAL REQUIREMENTS IN AUDITORIUM DESIGN

With the establishment of the Hong Kong Academy of Performing Arts and the planned Cultural Centre in Tsim Sha Tsui, acoutics for cultural centres has become a new topic of interest in town. Both of these new centre will have auditorium of high performance acoutics. The relatively sophisticated noise control system employed in the auditorium will be of major interest. This study will concentrate on the design of auditorium and its acoutical requirements.

I. TYPE OF AUDITORIUM

Auditoria can be classified as follow:

1. for speech
   eg. conference hall, lecture theatre, law court
2. for music
   eg. music pratice room, concert hall
3. multi-purpose
   eg. town hall, school assembly hall

II. ACOUSTIC FOR SPEECH

INTELLIGIBILITY = POWER + CLARITY

POWER is affected by

- diatance from speaker
- directional relationship to speaker
- audience absorption of direct sound
- reinforcement by reflectors
- reinforcement by loudspeakers
- sound shadows

CLARITY is affected by

- delayed reflections: echoes
  near echoes
  reverberation
- duplication of sound source by loudspeakers
- ambient noise
- intrusive noise

III. DISTANCE FROM SPEAKER

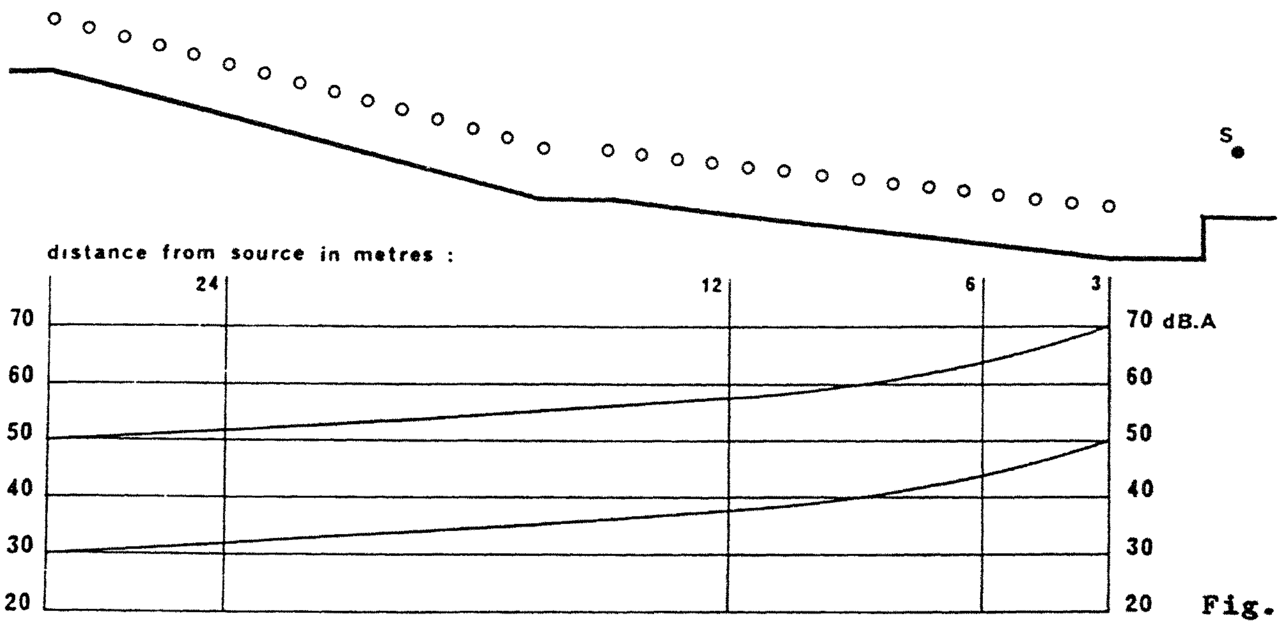


Fig.1

Fig. 1 shows the extent to which the sound of the human voice is attenuated by distance alone, in an auditorium with 30 rows of seats.

The importance of keeping the distance to rear rows of seats to a minimum is quite evident. Measures taken are:

1. economy in seat spacing
2. economy in row spacing
3. economy in gangway widths
4. optimum shape of audience area
5. introduction of a gallery

IV. DIRECTIONAL RELATIONSHIP TO SPEAKER

Speech intelligibility varied in accordance with the directional relationship of speaker to listener as shown by the 'equal intelligibility contour'.

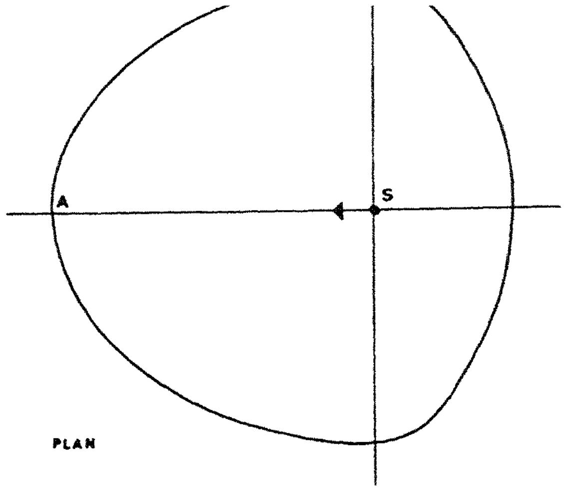


Fig.2

SA: up to 15m -- released listening

15m to 20m -- good intelligibility

20m to 25m -- satisfactory

30m -- limit of acceptability without electronic amplification

In reality, the speaker, or speakers, do not take up one position in relation to the audience

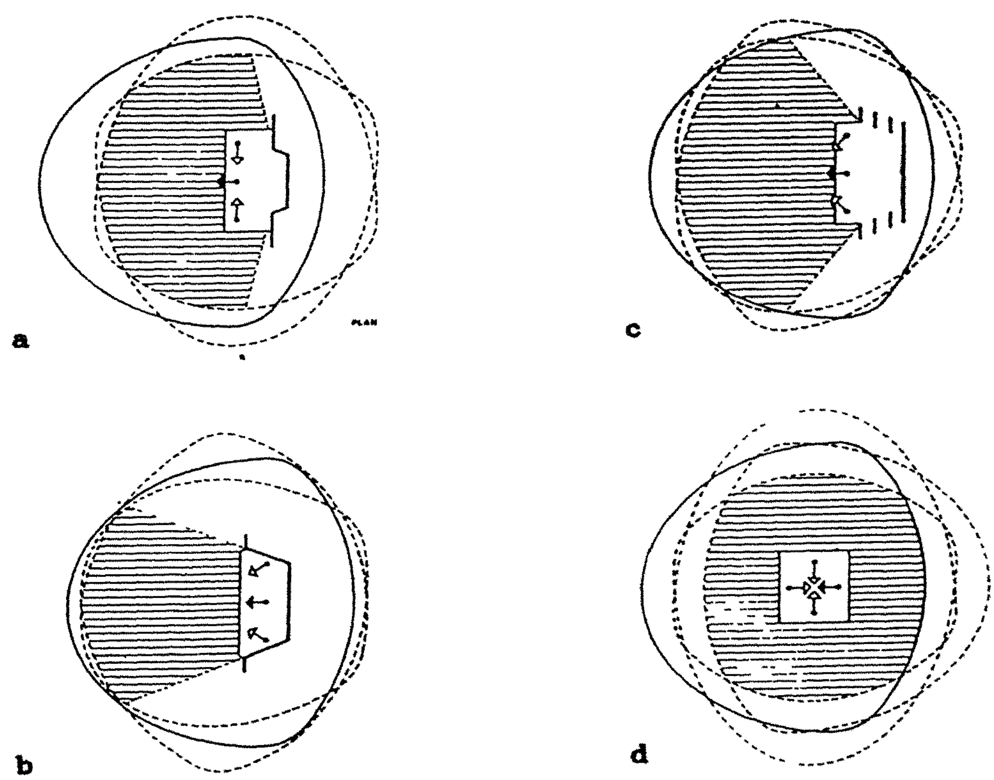


Fig.3

The optimum arrangement of seats will be within the shaded area enbraced by all three contours.

V. AUDIENCE ABSORPTION OF DIRECT SOUND

Audience absorption of direct sound can be reduced, and even eliminated by raking the floor because sound is more readily absorbed when it travel over the audience at grazing incidence.

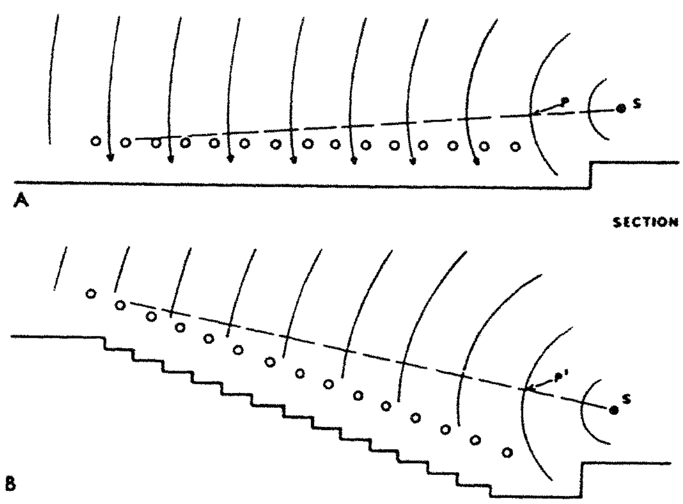
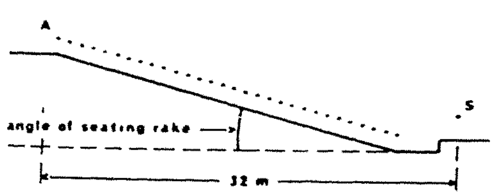


Fig.4

Fig.4 The initial sound wave reaching listeners in the rear row is well above the heads of listeners in the front rows and therefore subject to little or no absorption.



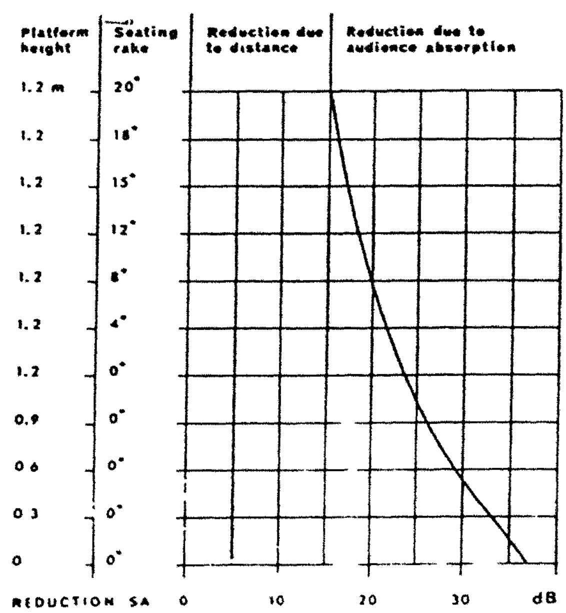


Fig.5

Method of establishing the slope of a floor that simultaneously provide good vertical sight line and a satisfactory flow of direct sound waves to the listener.

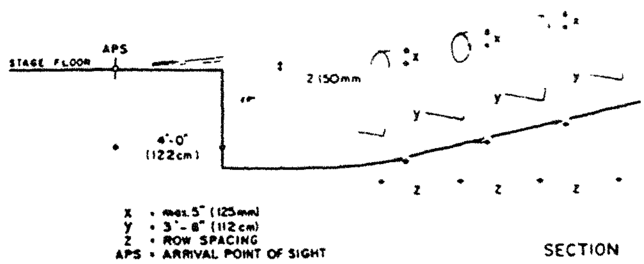


Fig.6

A more gentle slope can be achieved by considering:

1. raising the arrival point of sight (APS)
2. adequately reducing the value of X
3. observing two- row vision (instead of one row vision, which permits unobstructed view over the heads of the spectators in the row immediately ahead) and staggering the seats to allow a view between the heads of the spectators in the row immediately in front.

VI. REINFORCEMENT BY REFLECTORS

1. Sound source should be closely and abundantly surrounded with large sound-reflective surface in order to supply additional reflected sound energy to every portion of the audience area, particularly to the remote seats.
2. The dimension of the reflecting surface must be comparable to the wavelength of the sound wave to be reflected. Its minimum dimension should be of the order of 3m, so that the reflected sound is not materially weakened by edge diffraction.
3. The reflectors should be as low as possible so that the initial time-delay gap between direct and first reflected sound should be relatively short, possibly not exceeding 30 milliseconds.

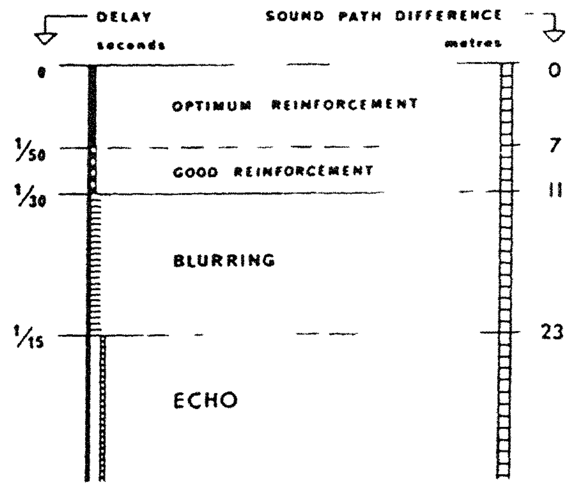


Fig.7

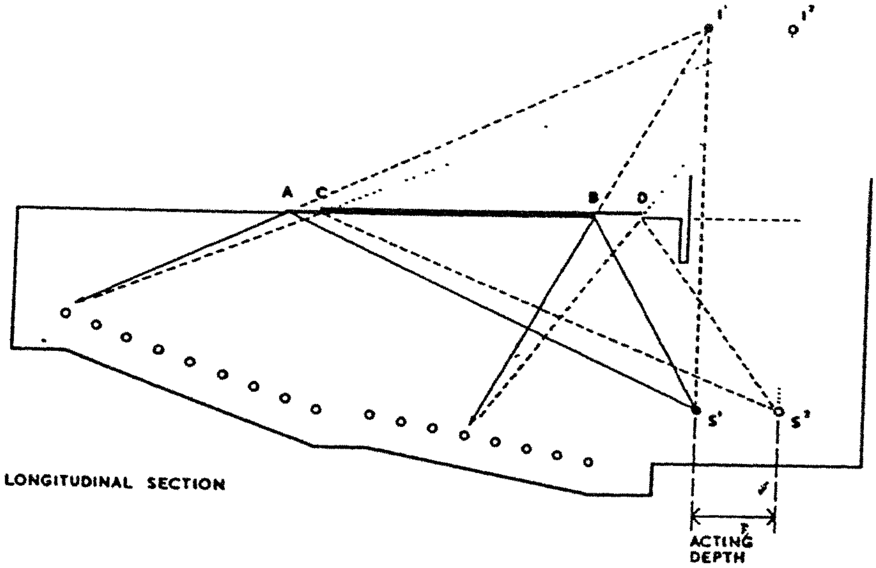
4. Good use can be made of the ceiling and wall surfaces in order to provide the greatest amount of short-delayed sound reflections.

5. The ceiling and the front portion of the side wall of the auditorium are always suitable surface for the accommodation of sound reflectors. The reflectors should preferably be overhead so that reflected sound is not reduced by audience absorption. Additional reflective surface must be provided which direct the sound back to the performers particularly true in auditorium designed for vocal purposes.

6. Correctly located sound reflectors also create an environmental condition known as space effect when a listener recieves sound from numerous directions.

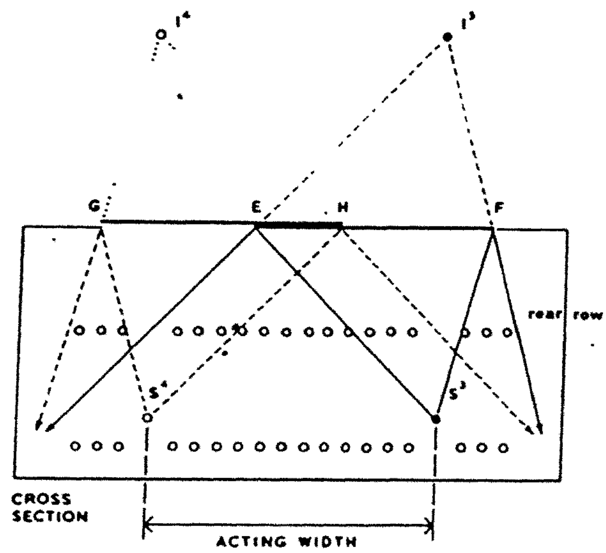
In large auditoriums, requiring fairly high ceilings may result in excessive delay between reflected and direct sound, suspended reflectors are frequently employed at a lower level.

Reflections from a convex surface are weaker as it is dispersive. A concave surface will strengthen reflections, but this may result in localising the reflections to the neglect of other areas of seating.



A
C
B
D
S¹
S²
LONGITUDINAL SECTION
ACTING DEPTH

Fig.8



G
E
H
F
rear row
S⁴
S³
CROSS SECTION
ACTING WIDTH

Fig.9

VII. REINFORCEMENT BR LOUDSPEAKERS

Sound amplification systems are used for the following purpose:

1. To reinforce the sound level in an auditorium or in outdoor locations when the sound source is too weak to be heard.
2. To provide amplified sound for overflow audiences.
3. To increase the sound level on the stage of an auditorium for the benefit of performers or listeners seated on the stage.
4. To provide the sound in motion-picture theatres
5. To minimize room reverberation
6. To provide artificial reverberation in rooms which are too dead for satisfactory listening
7. To provide a multitude of electroacoustical facilities in theatres and opera houses.
8. To operate electronic organs, chimes carillons, etc.
9. To reduce the masking effect of an excessive background-noise level in an auditorium or in the open air.

A sound system is expected to meet the following criteria:

1. It should properly transmit a wide range of frequencies (from about 30 Hz to about 12,000 Hz)
2. It should provide a wide dynamic range
3. It should be free from disturbing echoes or feedback
4. It should create a sufficiently low room reverberation
5. It should remain undetected.

VIII. LOUDSPEAKERS SYSTEMS

Three principle types of loudspeaker systems are available:

1. The centrally located system with a single cluster of loudspeakers over the sound source
2. The distributed system, using a number of overhead loudspeakers located throughout the auditorium
3. The stereophonic system, with two or more clusters of loudspeakers around the proscenium opening or the sound source.

The central (or front-of-the-room) system (Fig.10) gives maximum realism because the amplified sound comes from the same direction as the original sound.

Situations in which a distributed system (Fig.11) must be used:

1. In auditorium with a ceiling height too low for installation of a central system
2. Where a majority of the listeners would not have an adequate sight line to a central loudspeaker
3. When sound has to be provided for overflow audiences
4. In large halls where maximum flexibility is required to amplify sound source in any part of the hall and where the amplified sound has to override the prevailing high background-noise level
5. In halls where the possibility exists of dividing the space into several smaller areas

Stereophonic sound system presrves the illusion that the sound is coming from the original, unamplified source.

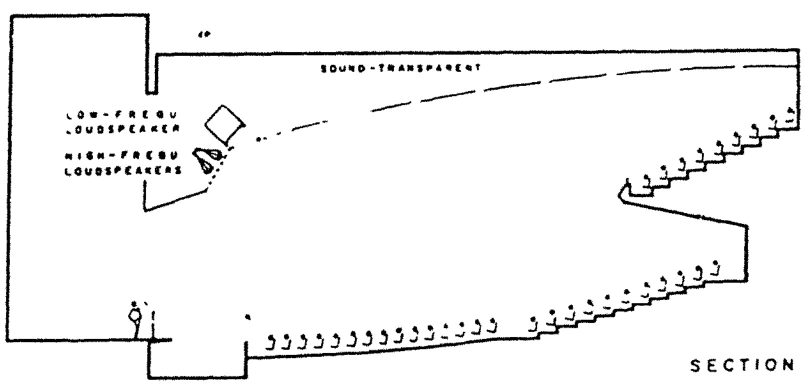


Fig.10

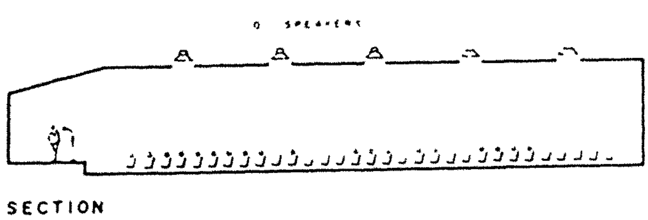


Fig.11

Most of the problems arising from the use of loudspeakers are a matter of loss of 'clarity'. There are three main types:

1. Introduction of even one loudspeaker in an auditorium means that members of the audience will bear two sound arriving at different times and from different directions. For both the central loudspeaker system and distributed loudspeaker system, the time intervals, as found by comparing the lengths of the sound paths, should be checked to ensure that they are not more than about 1/30 sec. (Fig.12)

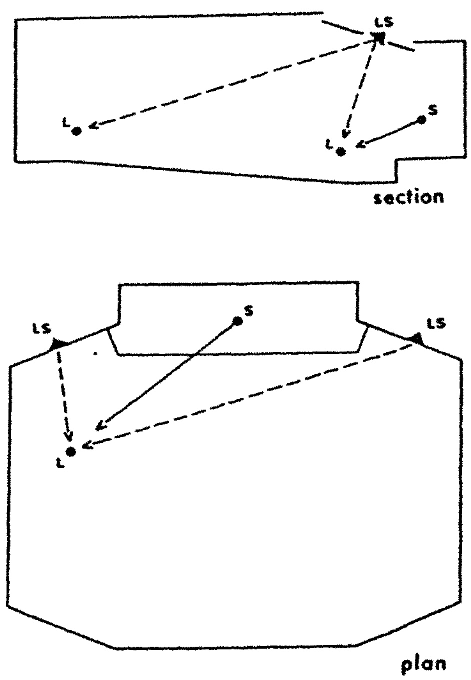


Fig.12

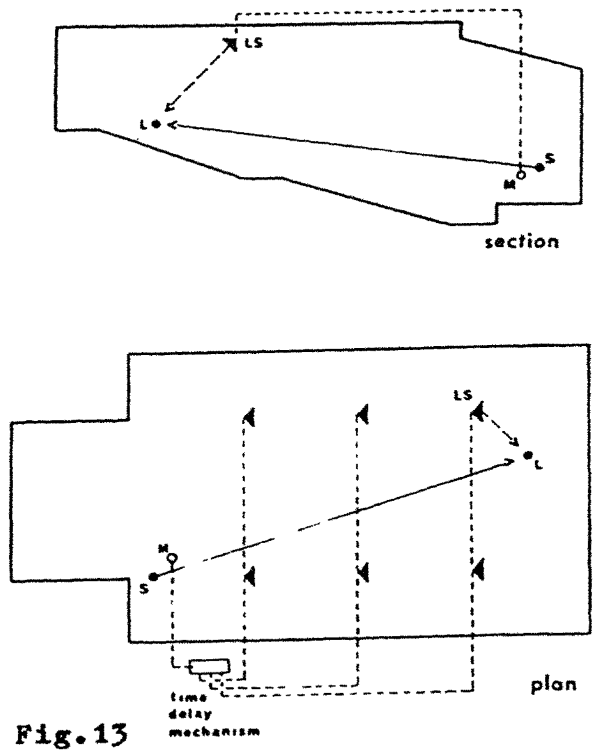


Fig.13

In the case of a centrally placed loudspeaker over the platform it is possible to avoid an undue delay by keeping it resonably low. In a wide auditorium the placing of loud-speakers at each side can cause an excessive delay.

2. The second problem arises when a loudspeaker is introduced half waydown a large auditorium . The sound reaching the listener from the speaker travels a 340m/s through the air. The sound emanating from the loudspeaker much closer to listener has travelled along a wire at the speed of light. He will hear the loudspeaker first and the sound from the platform either as a weak echoe or a blurring of the speech. The problem can be overcome by introducing a delayed mechanism into the loudspeaker circuit, so that sound from the loudspeaker is produced a few milliseconds after the arrival of the sound through the air. (Fig.13)
3. The use of 'column speakers' may cause a third problem, the possible increase of reverberation due to the incresed power of the sound. By 'fanning' most of the amplified sound over the highly absorbent audience this effect can be reduced.
4. The familiar problem of 'feedback' will occur if:
i. the sound radiate from the loudspeaker is picked up by the microphone
ii. reflective surfaces of the room are so located that reflected sound is concentrated on the microphone.
iii. the room is highly reverberant.

IX. SOUND SHADOW

Galleries should be kept shallow to avoid sound shadow.

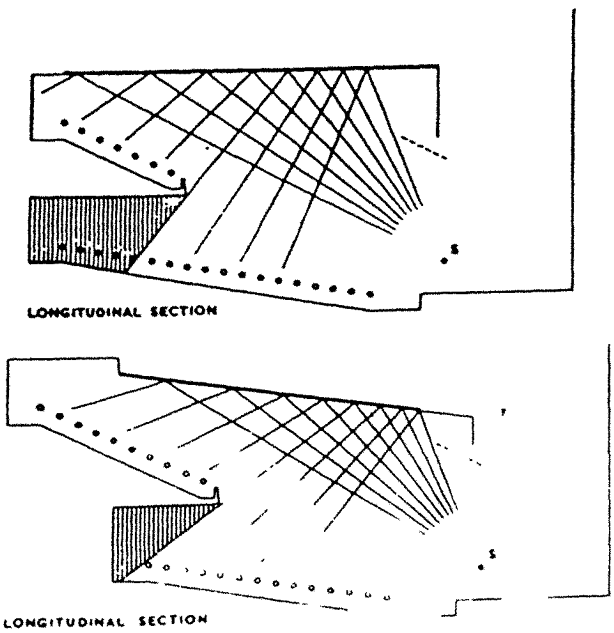


Fig.14

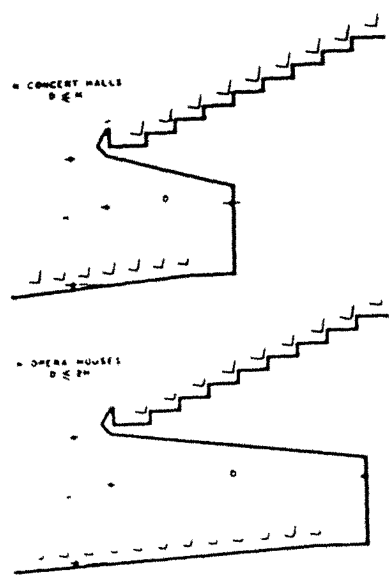


Fig.15

In these cases whe e delegates are allowed to epeak from their seated position, balconies should not overhang the main seating area to a low reflecting ceiling should be provided.

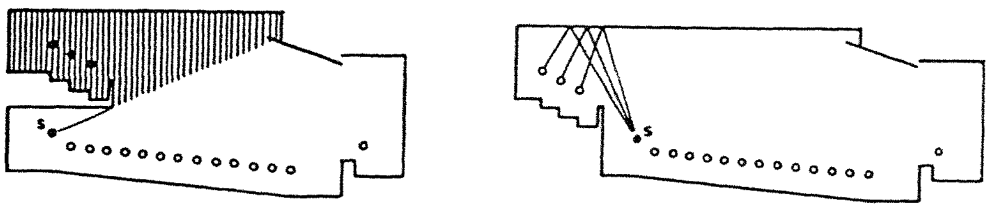


Fig.16

X. <u>DELAYED REFLECTIONS: ECHOES</u>

1. Echoe is noticable when the sound is being reflected from any boundary surface with sufficient magnitude and delay to perceive as a sound distinct from that travelling directly from source to listener.
2. Echoe occur if a minimum interval of 1/25 second (for speech) to 1/10 second (for music) elapses between the perception of the direct and reflected sound originating from the same source.
3. Echoe can be prevented by installing sound absorbing material along the defect-producing reflective surfaces. If using acoustical finishes along these area is not feasible, they should be rendered diffusive or tilted, in order to produce beneficial short-delayed reflections.

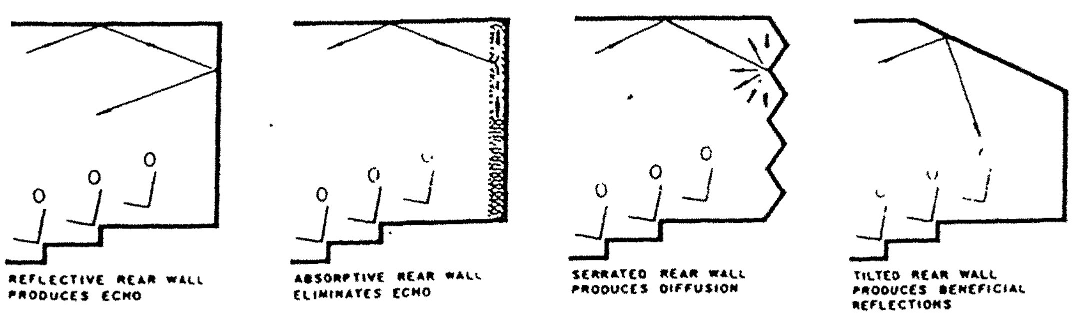


Fig.17

4. Echoe will be particularly noticeable if the reverberation time is short and diffusion is unadequate. The longer reverberation time will 'cover up' the single intrusions of an echoes.

XI. DELAYED REFLECTIONS : NEAR-ECHOES

A defect similar to echo except that the time delay between the perception of direct and reflected sound is somewhere less.

XII. DELAYED REFLECTIONS : REVERBERATION

The reverberation time is defined as the time for a sound to decayed by 60dB.

It depends on:

1. the initial power of the sound
2. the absorbency of surfaces or object with which it comes into contact during inter-reflection
3. the volumn of the interior and therefore the lenght of the sound paths.
4. the presence of any standing wave phenomena
5. the varying sensitivity of the ear at different frequencies

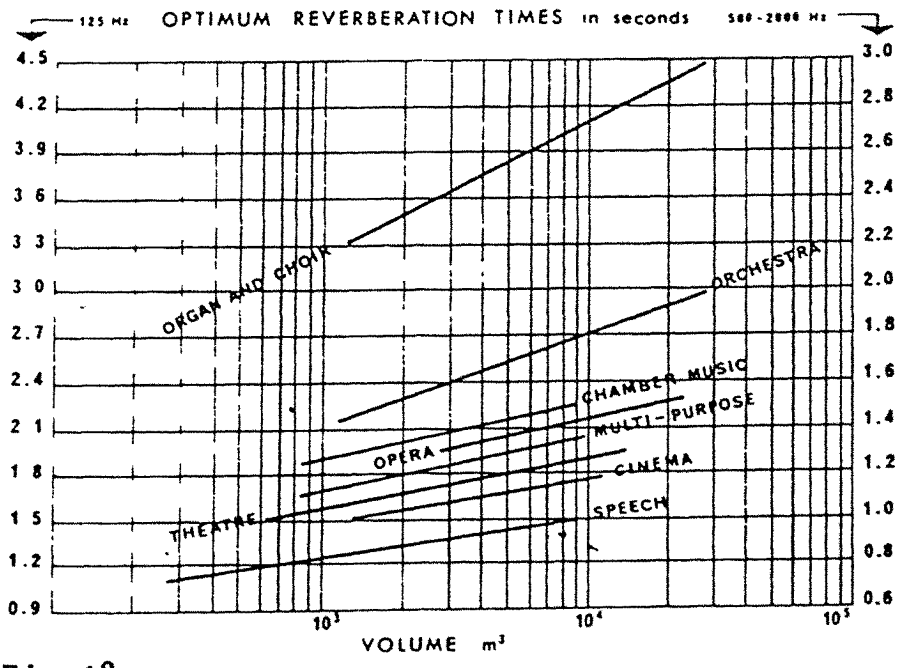


Fig.18

For good speech intelligibility, reverberation has to be controlled by the limitation of volumn and/or the introduction of absorbent material.

$$RT = \frac{V}{A} \times 0.1608$$

where RT = reverberation time, sec.

V = room volumn, m^3

A = total room absorption, m^2 sabin

Since the absorption of various materials and finishes used in the design of auditoriums usually varies with frequency, the RT value also vary with frequency.
In almost every auditorium the audience provides most of the absorption. But when attendence fluctuates widely, the more effective way is to replace the possible loss of audience absorption by upholstered seats.
The general effect of reverberation, if excessive, is to blur speech.

XIII. FLOOR SHAPES OF AUDITORIUM

1. Rectangular floor shape
   Cross reflectors between parallel walls contribute to increase fullmess of tones.
2. Fan-shaped
   -bring the audience close to the sound source
   -permit the construction of balconies
   -make good sight lines
   -the curved rear wall and the curved balcony front, when acoustically treated or rendered diffusive, are likely to create echoes or sound concentrations
3. Horseshoe-shaped
   -traditional layout of opera house
   -rings of boxes on top of each other, contribute efficiently to sound absorption, producing a relatively short reverberation time suitable for the rapid paerages of opera but short for orchestral performances.
4. Curvilinear
   -normally associated with a dome roof of excessive height
   -unless treated acoustically, curvilinear enclosure may create echoes, long-delayed reflections, and sound concentrations,all of which can contribute to an excessively long reverberation time should be avoided.
5. Irregular
   -can bring the audience unusually close to the sound source
   -can secure acoustical intimacy and difinition since surfaces used to produce short-delayed reflections can be early integrated into the overall architectural design.
   -free relationship between audience area and platform

XIV. ACOUSTICS FOR MUSIC

There are several room acoustical characteristics which affect the sound quality of music perform in the hall:

1. If the music gives the impression of being performed in a small, intimate hall the auditorium is said to have 'acoustical intimacy'. If the initial time-delay gap is shorter than 20millisec., and the direct sound is not too faint, the room will be found to be acoustically intimate.
2. If a auditorium has a large volumn relative to its audience capacity, with predominant sound-reflective enclosures, it is said to be 'live'. A live hall has a relatively long RT, giving a long sustain tone.
3. A hall has a relatively small volumn compare to its audience capacity with enclosures which are highly sound absorptive, is said to be 'dead' or 'dry'. A dry hall has a short RT, and music played in it will sound dull.
4. When the room have a relatively long RT at the lower frequencies, it has the fine acoustical quality of'warmth' resulting in rich brass.
5. If the RT is adequately controlled, a plaesant 'fullness of tone' will be noticeable. Excessive fullness of tone makes the sound blurred and unenjoyable.
6. If the sound of the different musical instruments are easily distincquishable, and if every sound within a rapid passage is heard separately, the room is said to possess 'definition' or 'clarity'. Good definition will prevail if a considerable amount of short-delayed reflection have been provided.
7. If reflected sound waves approach the listener from every direction in approximately equal amount, the result is 'diffusion'. A relatively long RT and ample wall and surface irreqularities promote diffusion, a highly dèsirable characteristics in auditorium for music.
8. Another important feature is 'balance'. It can be achieved by numerous sound-reflective and sound diffusive surfaces around the sound source to strengthen and improve the balance between the various sections of the orchestra.

9. If musical sound are well mixed before they reach the listener, so that they are percieved as harmonious, it is said to have good 'blend'.
10. If the musicians and the soloist have the ability to perform in unison so that the entire orchestra sounds as a co-ordinated unit, the music hall is said to possess 'ensemble'.
11. Freedom from noise, that is ,the reduction of exterior and interior noises to inaudibility, is one of the most important requisities in auditoriums for music.

XV. EFFECTS OF ROOM ACOUSTICS ON MUSIC

Investigations make it clear that music required a definitly longer RT than speech. A resonable degree of blurring and overlapping in musical sounds is often considered acceptable and even desirable.

For various styles of music, it is found that:

1. RT about 1.0 sec. is ideal for baroque music
2. 1.5 sec. is recommended for classical and mordern music
3. about 2.0 sec. is preferable for romantic music

XVI. ARHITECTURAL DESIGN OF MUSICAL AUDITORIUMS

1. Since no music hall is built for one specific type of music, RT must always be a compromise.
2. Definition will be satisfactory if the initial time-delay gap does not exceed 20millisec.
3. To achieve uniform quality of sound over the entire seating area balconies should not protrude too deeply into the air space of the room.
4. Echoe will be particularly noticeable if the RT is short and diffusion is inadequate. Longer RT of the room, less trouble from echo.
5. Particular attention is required to control noises and vibrations originating from the heating, ventilating and air-conditioning ayatems.

XVII. OPERA HOUSES

1. Opera house is the combination of a legitimate theatre and a concert hall.
2. Opera houses use procenium stages with the obvious consequence of separation between performers and spectators.
3. To secure an adequate balance between orchestra and singers the projecting forestage should not cover more than about one-third of the orchestra pit floor area.
4. The stage floor of most European opera house was raked in order to improve spectator's and conductor's viewing and to accentuate the perspective of the painted scenery.
5. Provision for an apron stage protruding into the audience area is recommended, to reduce the average distance between singers and audience and render t e ceiling reflectors more effective in the supply of short-delayed reflections to the audience.

CASE STUDY : HONG KONG ACADEMY FOR PERFORMING ARTS

Facilities worths about $86.40 million for noise and vibration resistance are installed in the Hong Kong Academy for Performing Arts, accounting 1/3 of the total construction cost of the project.

300mm thick concrete walls are erected to be panelled in two glass sheets each 200mm thick.

Each of the major rooms are structurally segregated from the principal building structure with its own ceiling and flooring system, forming a 'box-in-box' construction.

Rubber cushions 200mm thick are mounted on the platform of the complex to minimize the vibration caused by the passing MTR trains underground.

The following analyses concentrated on the room acoustics of the main thatre in the Academy which are designed primarily for opera performances but can occassionally be used as concert hall.

I. THE PLAN

The main theatre with polygonal floor shape, having an orchestra lift pit in front of the stage, and three sets of seats for the audience:the stall, the circle, and the gallery.

The irregularities shown in the plan at the side walls avoid blank walls which will give a concentrated reflected sound. The irregular wall will help to diffuse the sound, which will give a good blend of the music.

Detail design of the plan will be shown in the following Fig.a, b and c.

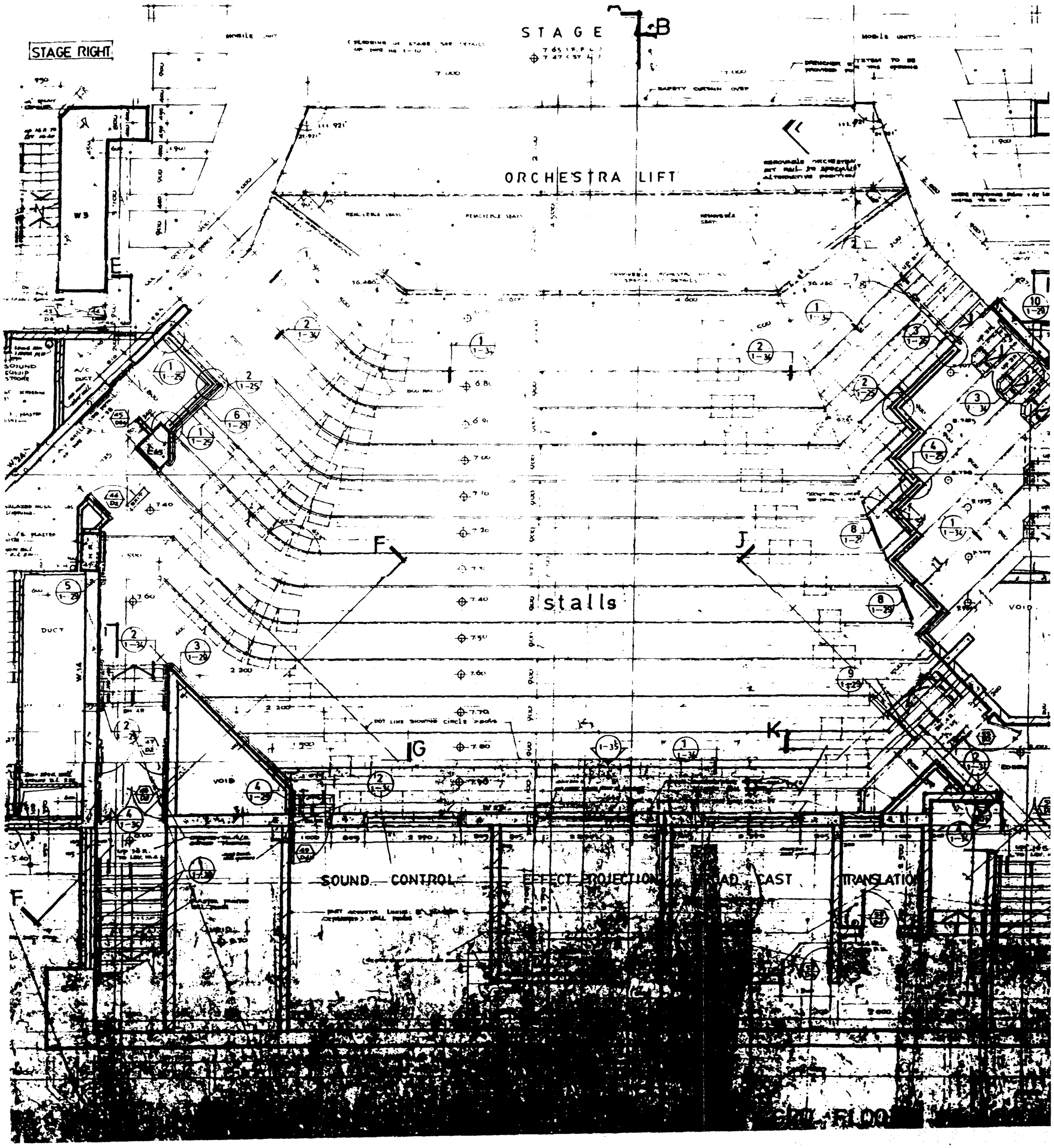
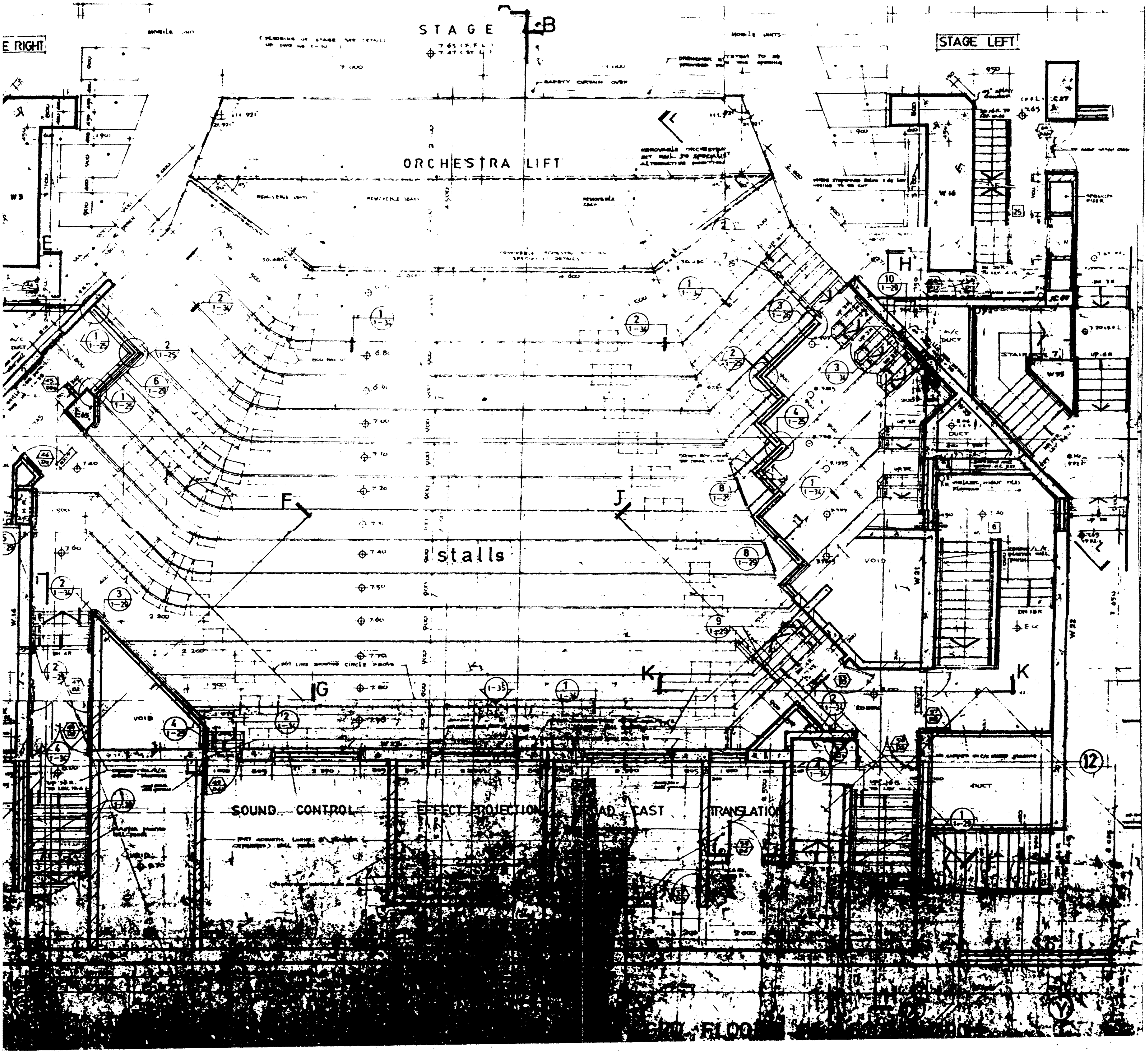

STAGE
STAGE RIGHT
B
ORCHESTRA LIFT
stalls
DUCT
VOID
SOUND CONTROL
EFFECT PROJECTION
CAST
TRANSLATION
F
G
J
K

Fig. a


STAGE
B
STAGE LEFT
ORCHESTRA LIFT
stalls
SOUND CONTROL
EFFECT PROJECTION
TRANSLATION
VOID
DUCT

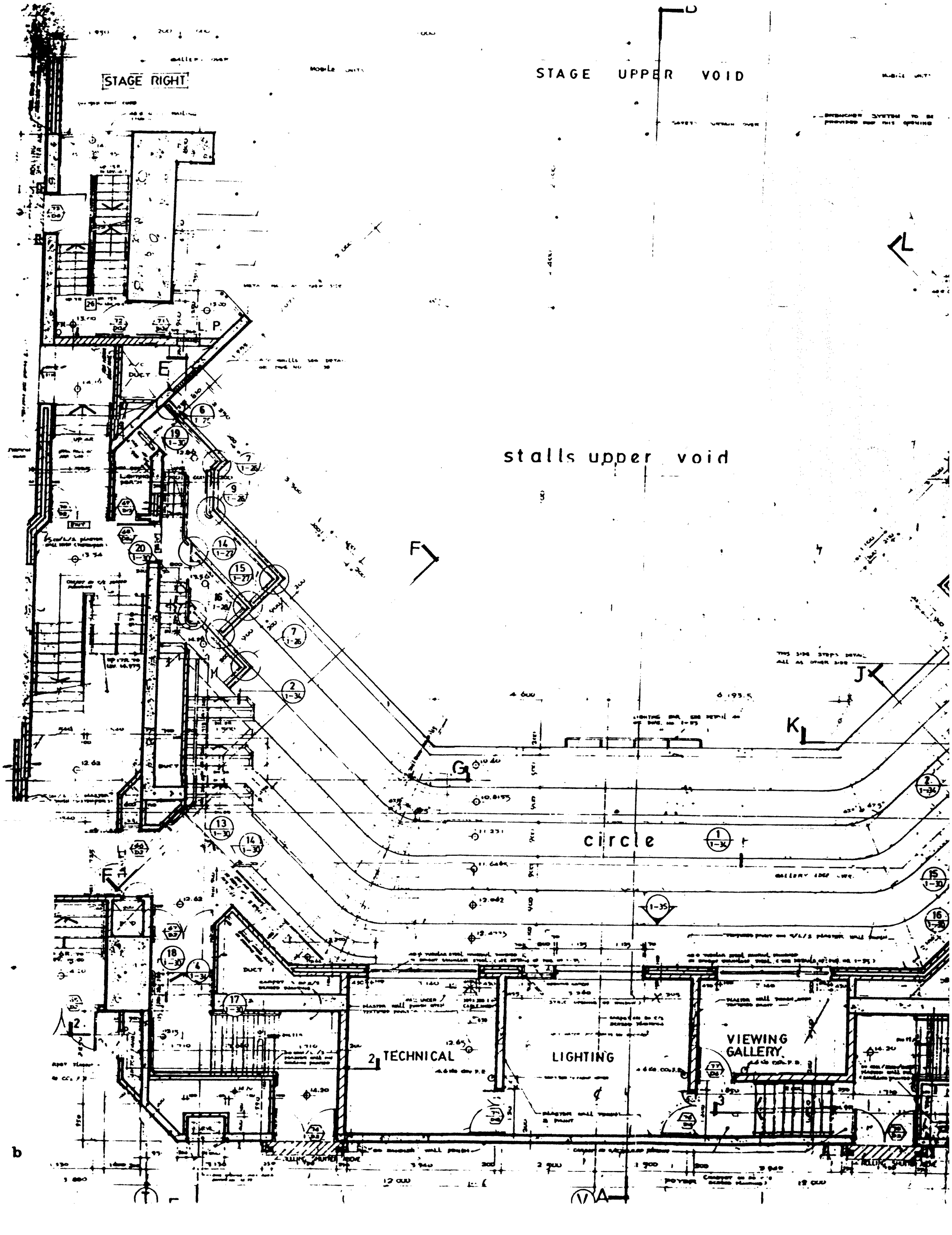
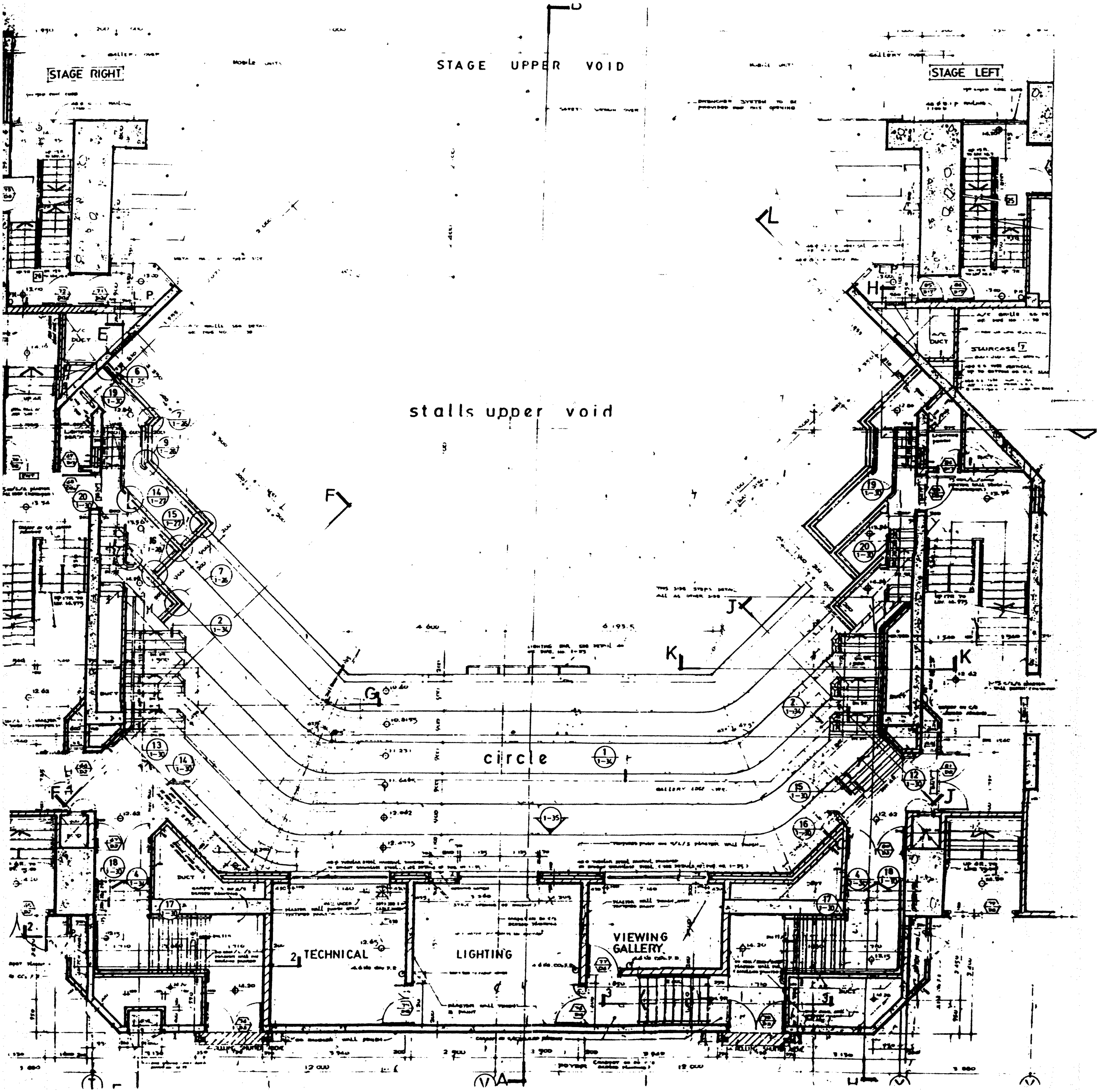

STAGE RIGHT
STAGE UPPER VOID
stalls upper void
L.P.
DUCT
circle
TECHNICAL
LIGHTING
VIEWING GALLERY

Fig. b


STAGE RIGHT
STAGE UPPER VOID
STAGE LEFT
stalls upper void
circle
TECHNICAL
LIGHTING
VIEWING GALLERY

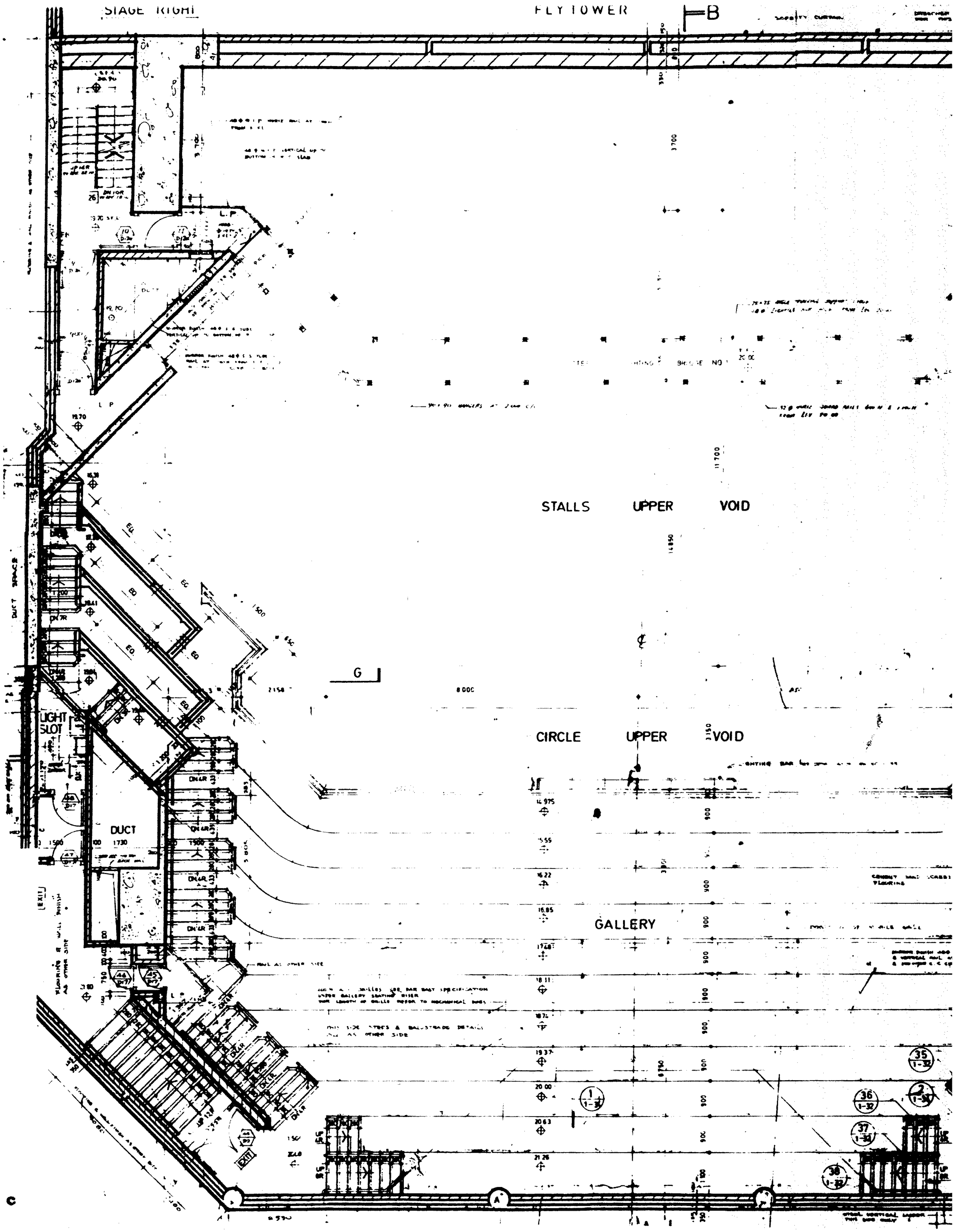
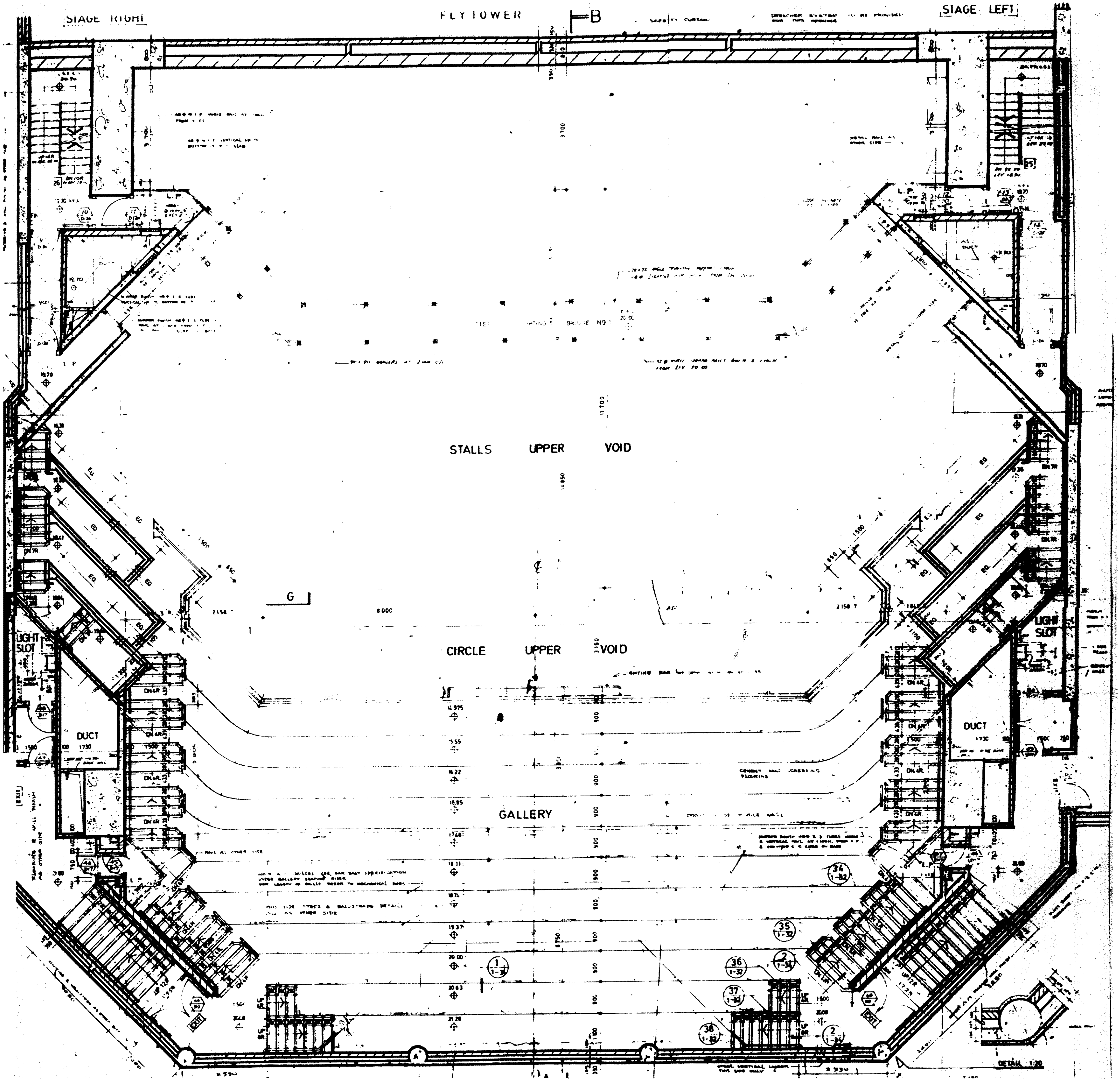

STAGE RIGHT
FLYTOWER
B
STALLS UPPER VOID
G
CIRCLE UPPER VOID
GALLERY
LIGHT SLOT
DUCT
DUCT SPACE
EXIT

Fig. c


STAGE RIGHT
FLYTOWER
B
STAGE LEFT
STALLS UPPER VOID
G
CIRCLE UPPER VOID
LIGHT SLOT
LIGHT SLOT
DUCT
DUCT
GALLERY
EXIT
DETAIL 1:20

II. THE SECTION

The main acoustical treatment of the main theatre is the false ceiling. It takes up the funtions of:

1. reducing the volumn of the main thatre in order to get the correct reverberation time and shorten the path of reflected sound to the audience
2. providing surfaces of absorption for correct reverberation time and reflection for reinforcement of sound from its source
3. providing a profile which is beneficial to the acoustic of the theatre
4. concealing the air-conditioning and lighting layout

Fig.d and e shows the seating arragement of the stall, the circle and the balcony and the profile of the false ceiling in greater detail.

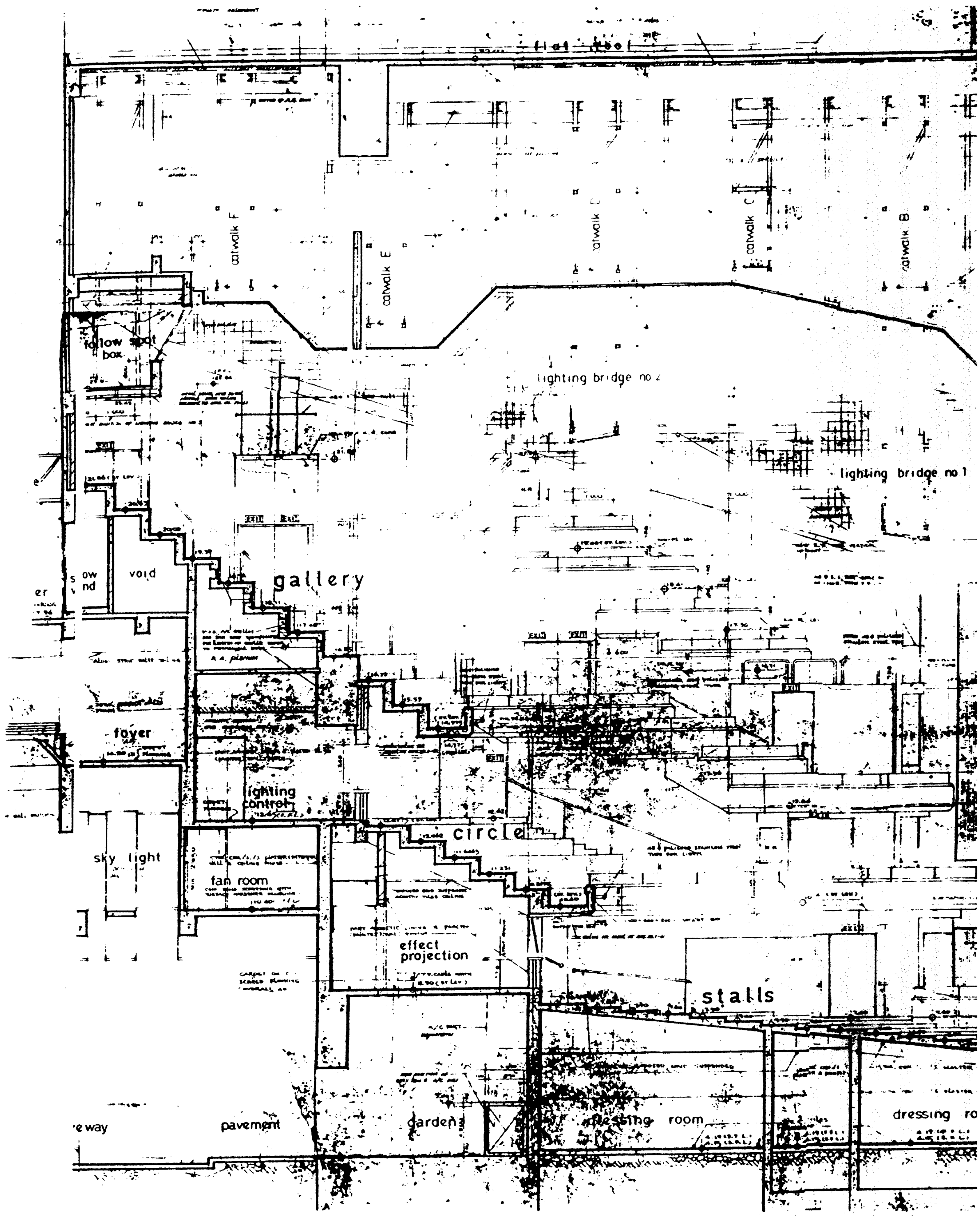
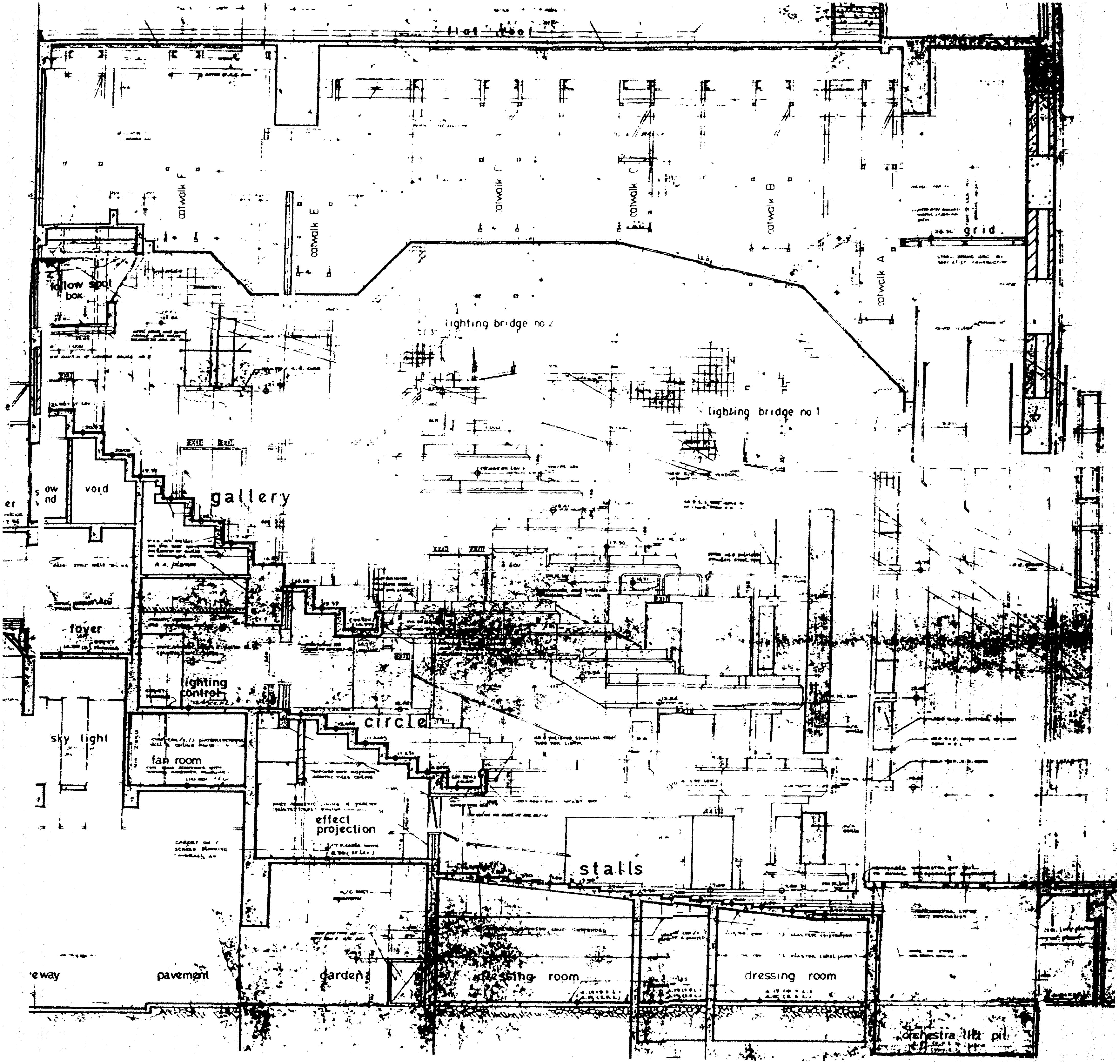

flat roof
catwalk F
catwalk E
catwalk C
catwalk B
follow spot box
lighting bridge no 2
lighting bridge no 1
void
gallery
foyer
lighting control
sky light
fan room
circle
effect projection
stalls
pavement
garden
dressing room

Fig. d


catwalk F
catwalk E
catwalk A
grid
follow spot box
lighting bridge no 2
lighting bridge no 1
gallery
void
foyer
lighting control
circle
sky light
fan room
effect projection
stalls
pavement
garden
dressing room
dressing room
orchestra lift pit

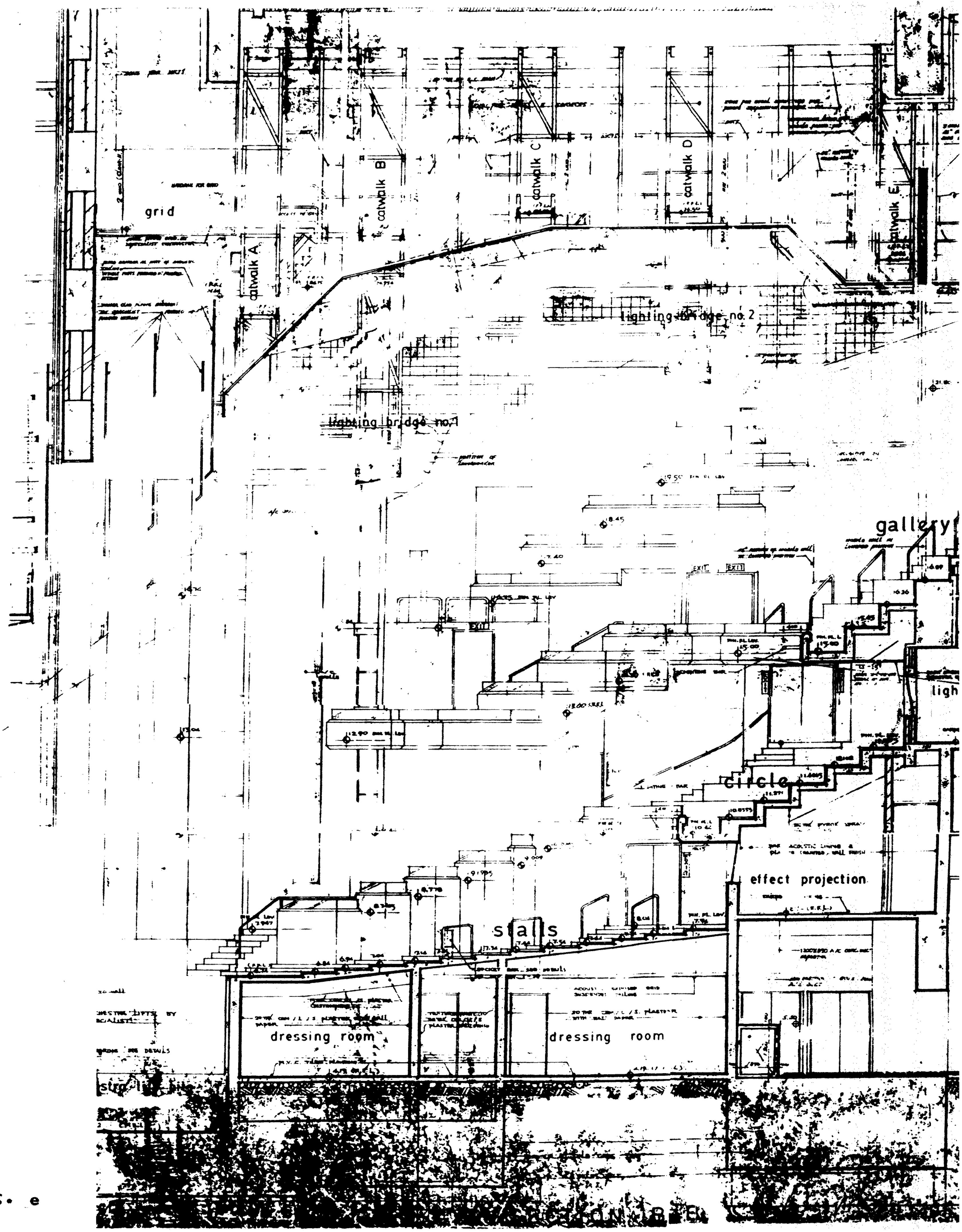
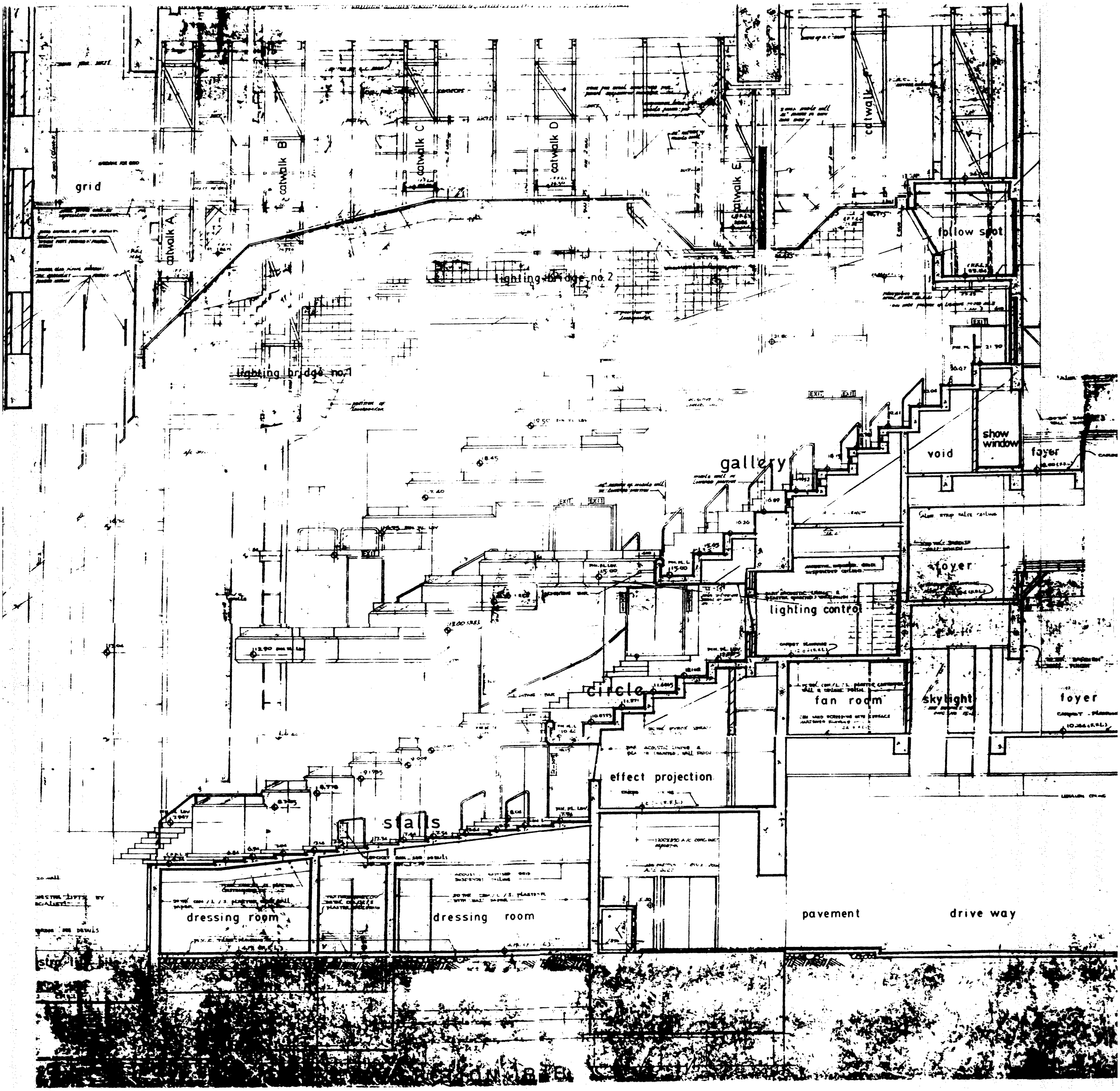

grid
catwalk A
catwalk B
catwalk C
catwalk D
catwalk E
lighting bridge no.2
lighting bridge no.1
gallery
EXIT
circle
effect projection
stalls
dressing room
dressing room

Fig. e


grid
catwalk A
catwalk B
catwalk C
catwalk D
catwalk E
catwalk
follow spot
lighting bridge no.2
lighting bridge no.1
gallery
void
show window
foyer
foyer
lighting control
circle
fan room
skylight
foyer
effect projection
stalls
dressing room
dressing room
pavement
drive way

III. DETAIL OF SUSPENDED CEILING

1. The false ceiling is constructed of 25mm thick marine plywood sheets suspended from channels and hangers attached to the principal structure. (In practice, it is constructed of two 12.5mm thick plywood sheet glued together owing to the lack of supply of the 25mm thick plywood sheets)
2. The channel and hanger is joined to the structure through neoprene pads and the false ceiling is of a certain rigidity and separated from the structure to prevent the enclosure of an air drum which will be set into vibration by the passing of the MTR trains under the Academy.
3. A mobile wall is presented in the main theatre so that the volumn of the theatre can be reduced and the reverberation time be corrected when the number of audience is smaller and the absorption is consequently reduced.
4. Parallelism between opposite sound-reflective boundary surface is small and it is lessen by the irregularities of the seating arrangement in the circle and the gallery which help to diffuse sound to eliminate the effect of flutter-echo.

The following pages show the detail construction of the ceiling.

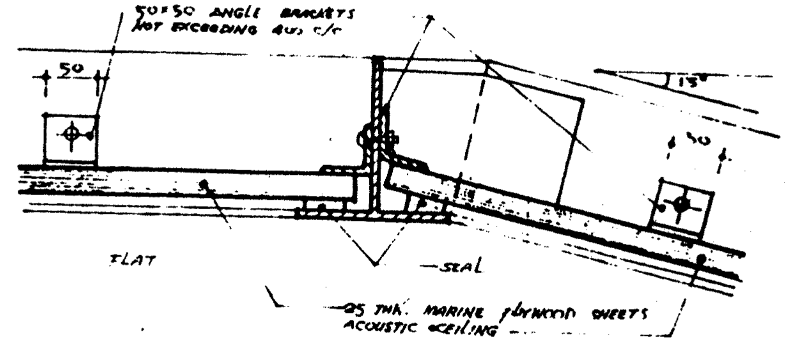


Fig.f Detail between Flat and 13°angle

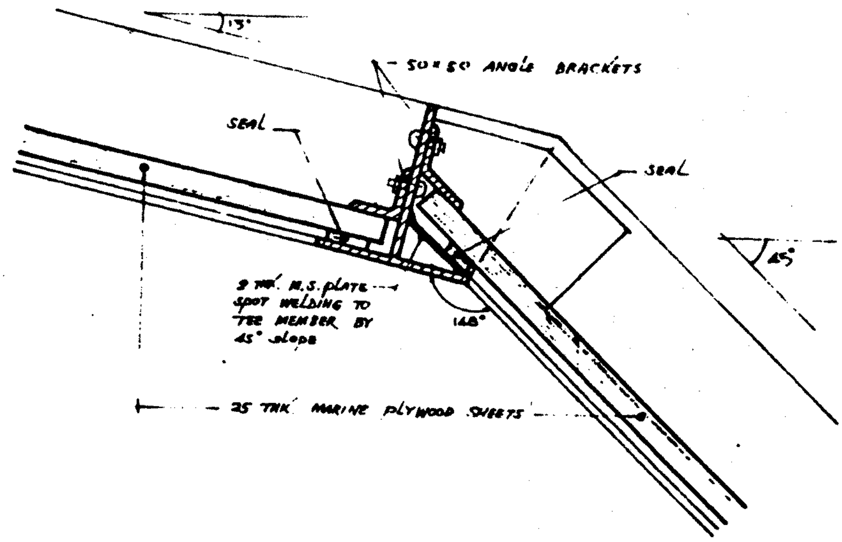


Fig.g Detail between 13°and 45°angle

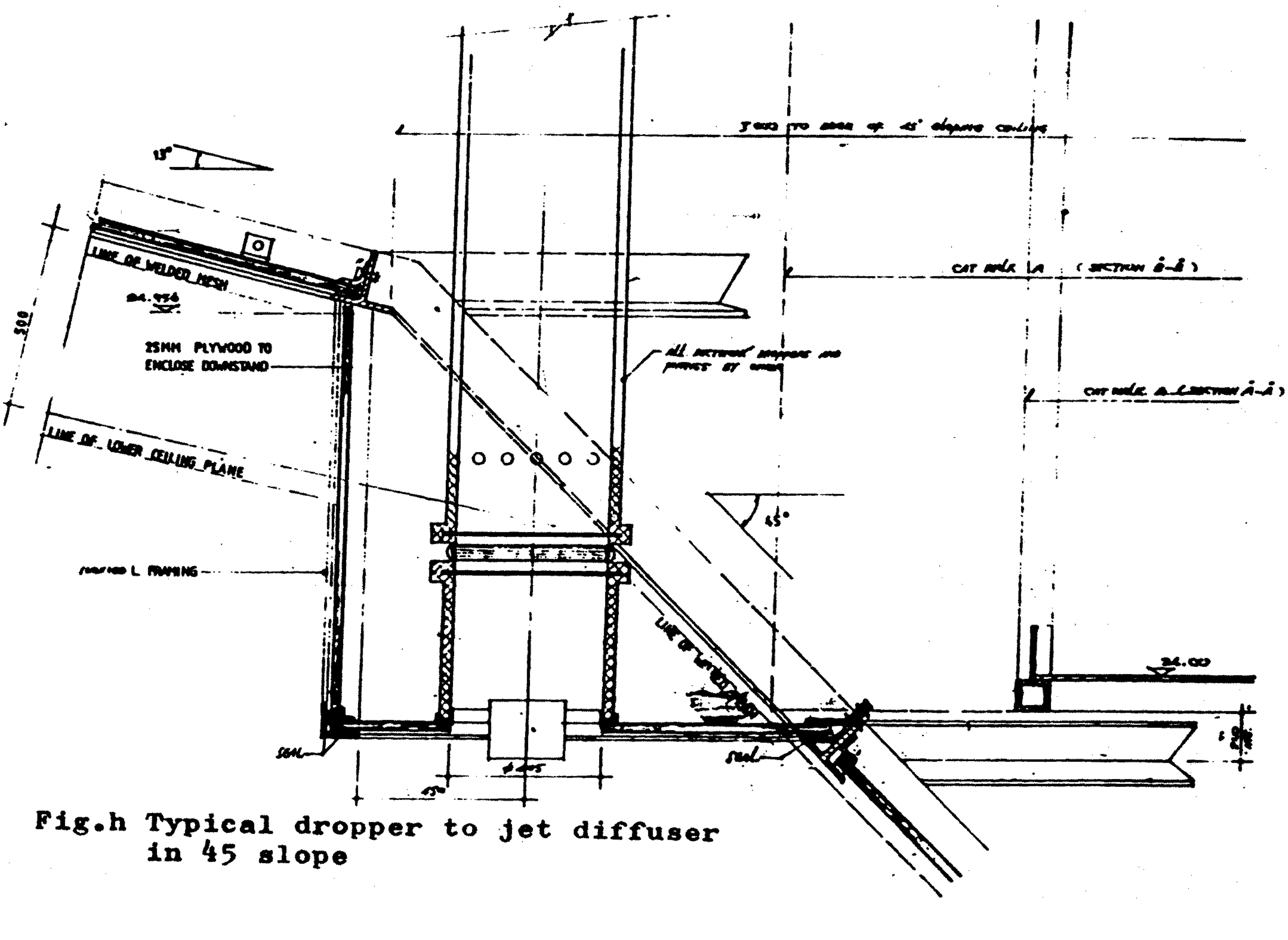


Fig.h Typical dropper to jet diffuser in 45 slope

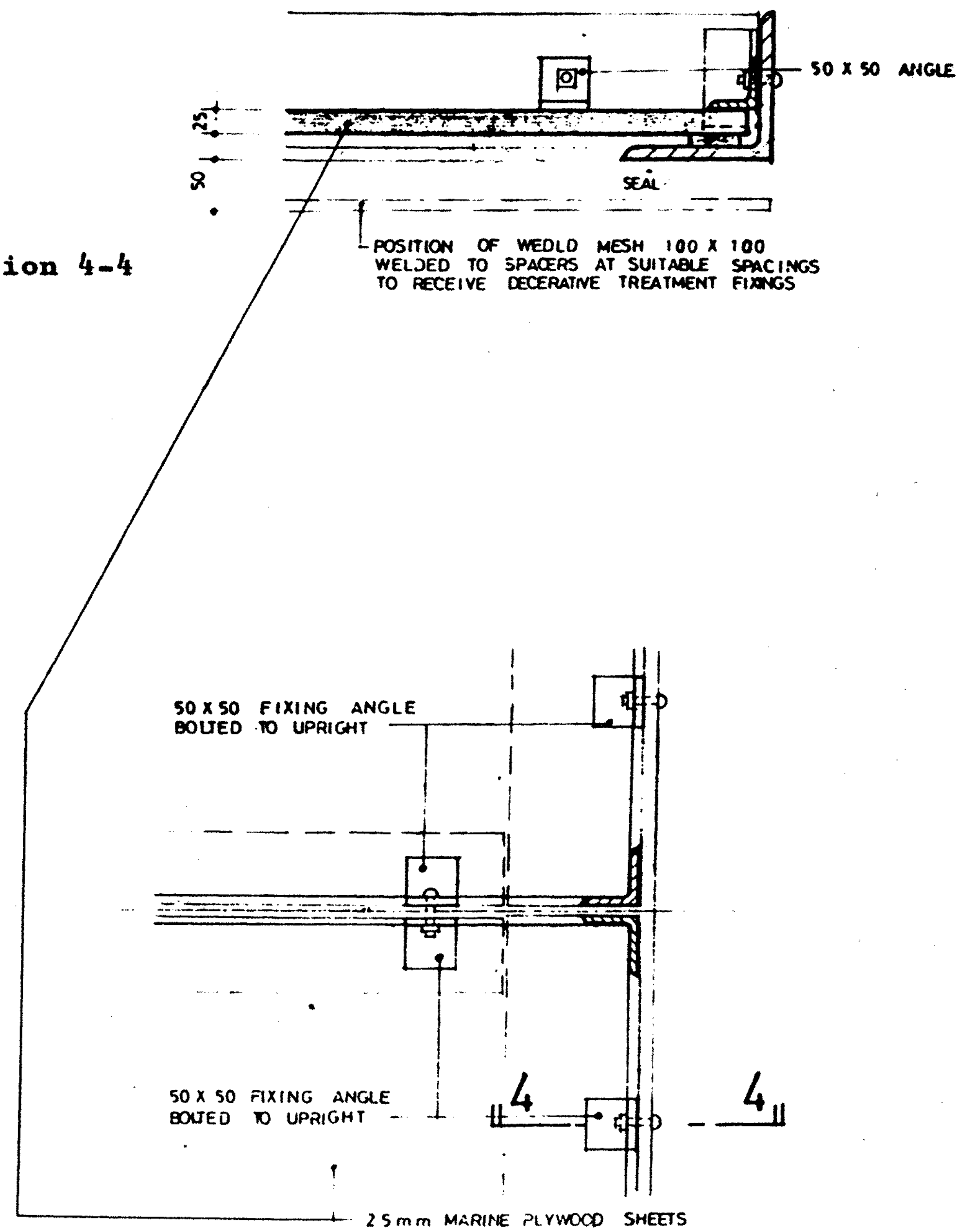


Fig.i
Typical Detail for Tee to Angle at Edge of Ceiling by Mobile Wall

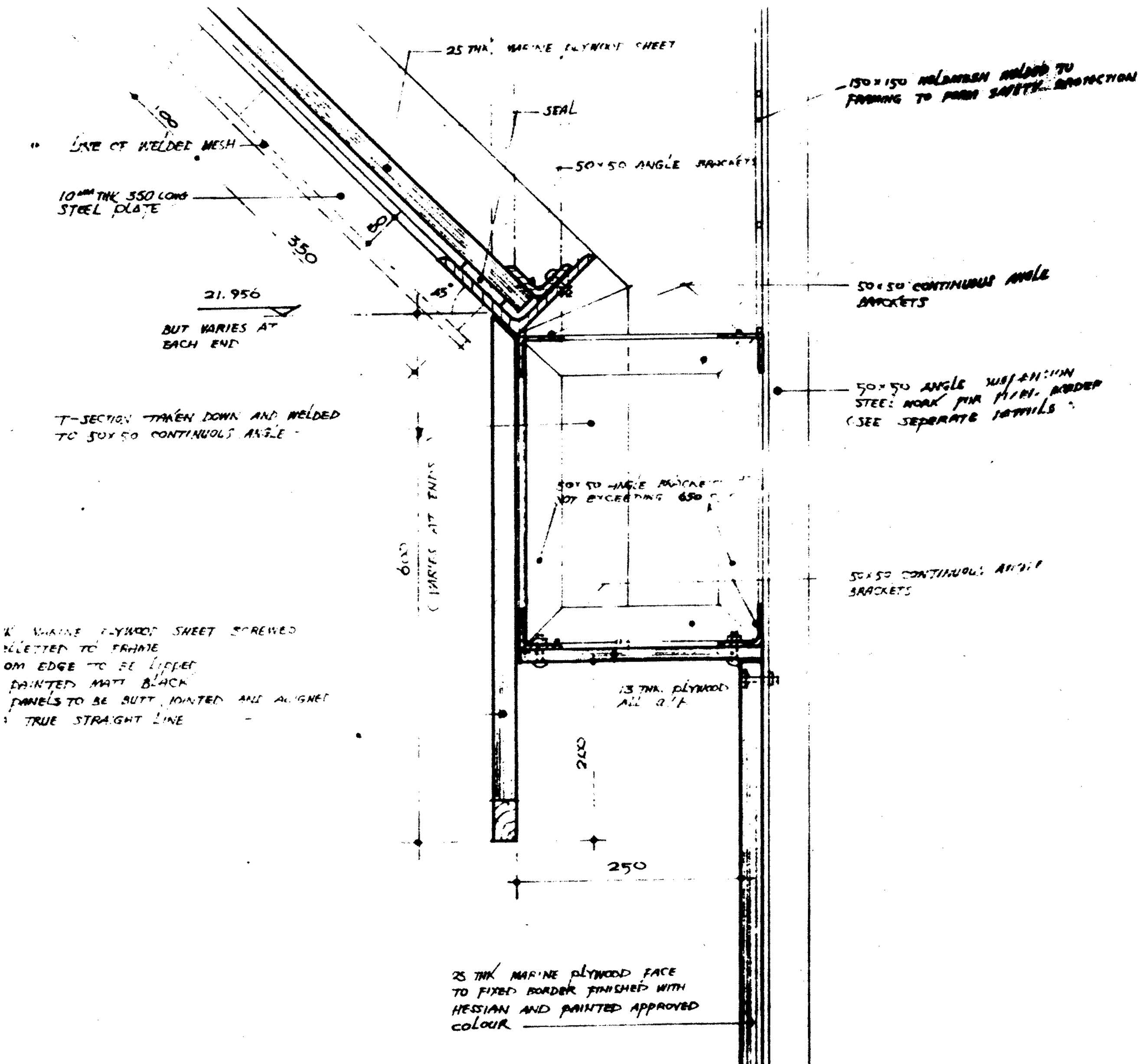


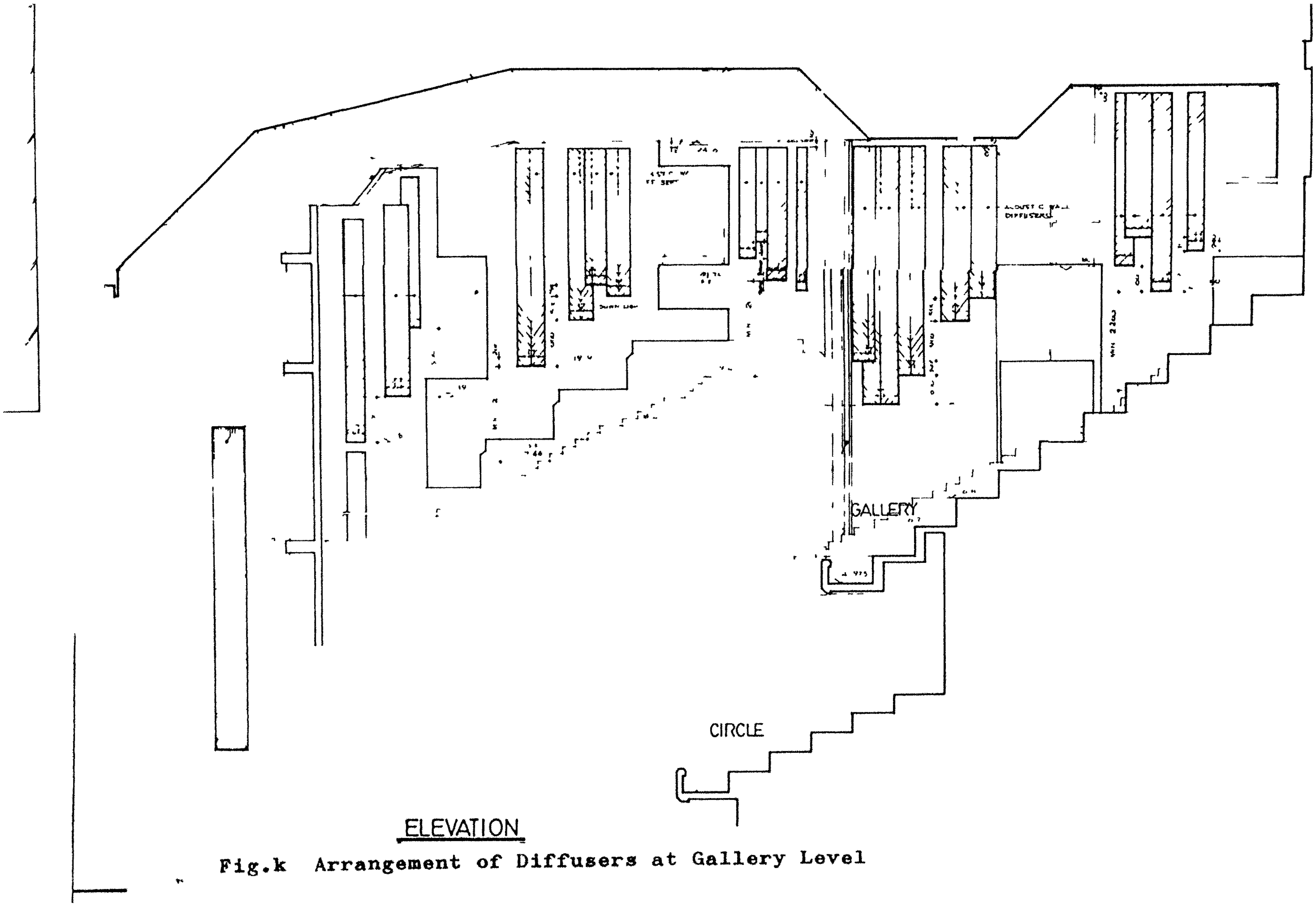
Fig.j

Typical Section through Front Edge of Ceiling over Forestage

IV. DETAIL OF ACOUSTIC WALL DIFFUSERS

1. Acoustic wall diffusers are also attached to the flank wall to provide diffusion to improve the hearing condition and help to break up the two blank parallel walls.
2. Upholstered seats and carpet in the theatre improve the sound absorption of the theatre, reducing reverberation time for small audience and at rehearsal and lessen the problem of ambient noise.
3. Fiber glass acoustic absorbent is fixed to the underside of the ceiling to prevent the penetration of intrusive noise to the theatre particularly against the noise produced by the helicopter landing pad near to the Academy.

The following drawings will show the detail construction of the diffusers.



ELEVATION

Fig.k Arrangement of Diffusers at Gallery Level

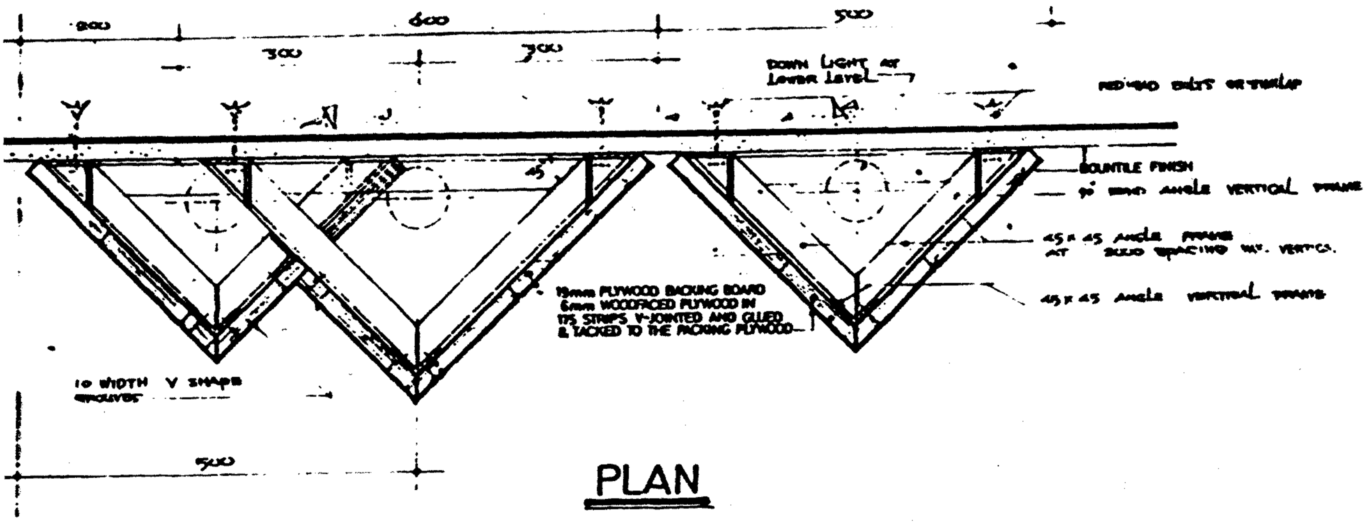


Fig.1 Detail of Acoustic Wall Diffuser

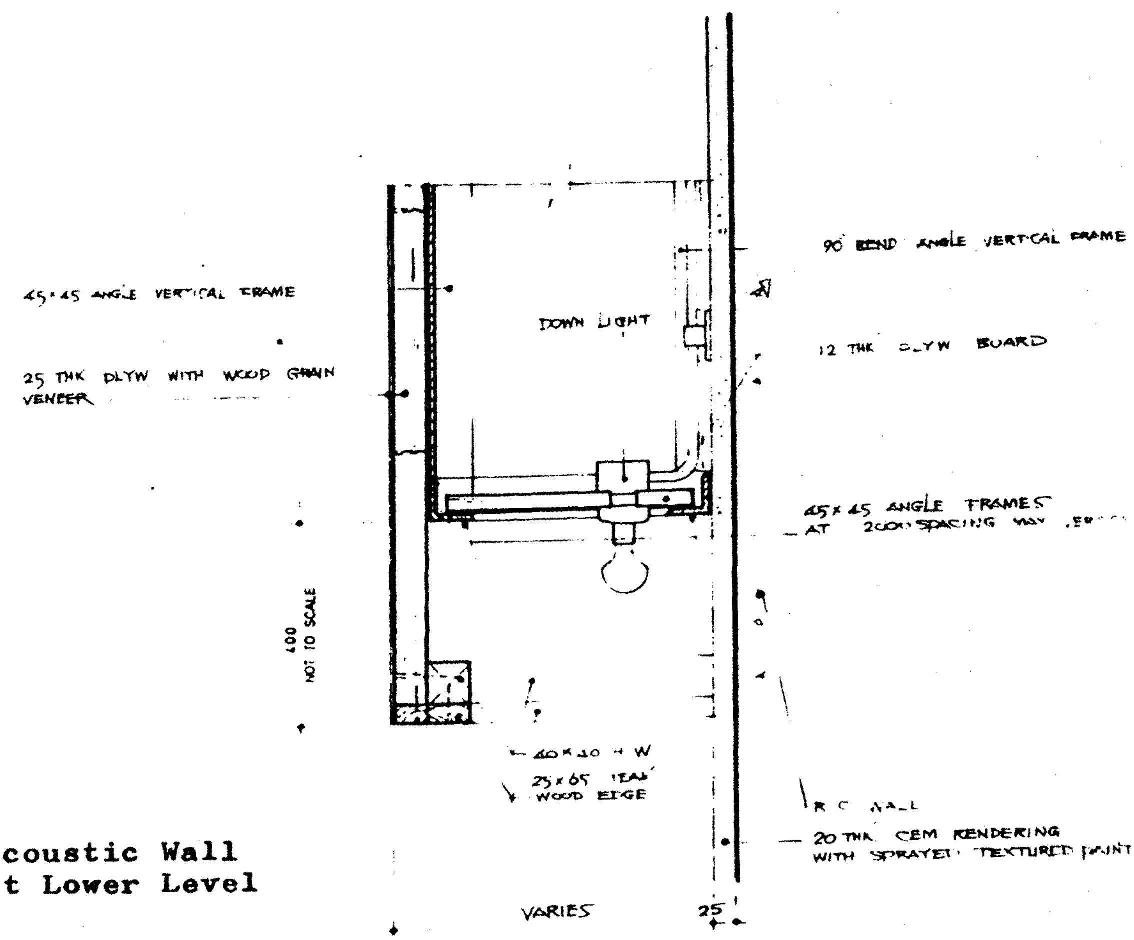


Fig.m
Detail of Acoustic Wall
Diffusers at Lower Level

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   'SOUND' WAY TO NOISE CONTROL
   DAVID G. LEES

REMARKS

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Cameras are prohibited in the Auditorium of the Hong Kong Academy for Performing Arts. Illustrations are therefore by drawings and diagrams.

Date Due	Date Due	Date Due

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