The Sub-Stage Orchestral Environment:

The Pits?

by

Pierre Schuster

This dissertation is submitted in partial fulfilment
of the requirements for the degree of Master of Music
at the University of Cape Town

1992

PREFACE

My choice of subject for this thesis was in a sense fortuitous, although it obviously reflects my career and interest in my own workplace. Far less predictable was the depth of concern and cooperation I received from people involved in the construction and management of the Nico Malan Theatre Centre in Cape Town. First among these is Maciek Miszewski, architect; second is Dr. Wilhelm Keet, acoustician, who co-supervised this thesis. Other architects and acousticians who helped directly were John Rennie, Jack Barnett and Jan Burger (Akoestiplan). Most important of my other primary sources were Pieter de Swardt, Technical Director of CAPAB, and Pieter Conradie and Piet de Villiers, both of C.A. du Toit & Partners, consulting engineers.

During the past two years I have met nothing but openness in my dealings with CAPAB, and was privileged to have the opportunity to confer with Veronica Paeper of Ballet, Angelo Gobbato of Opera, and Graham Coote of Music. In addition, material assistance was offered by Johan van Pareen and his son (air-conditioning), Steve Williams (mechanical), and Jeff Japhta (sound). I had aid in consultation from the distingiushed conductors Terence Kern and Reinhard Schwarz.

The intellectual and medical assistance received by Dr. Jonathan McKiever (chiropractor) is much appreciated. Thanks also to Karl Koperski; Allison Rubia and her staff at U.C.T.'s Music Library; and Bonny White of Bishop's Preparatory School Music Department, who did the drawings. I must also acknowledge the special part Jill Beer played in the production of this thesis; her patient instruction and invaluable knowledge of computer technique contributed greatly to the the presentation of this work.

Finally, hearty thanks to Sean Kierman, my direct supervisor at University of Cape Town. Without his enterprise and drive, this thesis would surely not have seen light of day.

TABLE OF CONTENTS

To Sean

ABSTRACT

The primary objective of this thesis is the exploration of the orchestra pit environment. Three analytical elements establish the purpose for this examination. First, a historical review serves as an essential guide to understanding how and why the contemporary orchestra pit milieu emerged. Second, by relating this sub-stage environment to the rest of the auditorium, fundamental principles of design become evident. The success or failure of an opera pit depends directly upon these principles. Third, the examination of individual features of design in relation to these principles forms the basis for refined critical assessment.

Since its inauguration in 1971, the orchestra pit at the Nico Opera House in Cape Town has undergone numerous alterations, affecting both the physical and acoustical environment. An analysis of the effects of these modifications demonstrates, and indeed confirms, the benefits of using a structured approach, as suggested above, when appraising a sub-stage environment.

Inevitably this thesis deals at least obliquely with the interface between the building design and the human factor, and much of this implicates management and the decision-making process. It is hoped that this treatise will assist in establishing parameters for real decisions about pits for orchestras in the future.

INTRODUCTION

Getting a job as an orchestral musician is a minor miracle in this day and age, despite the long training and discipline necessary to achieve ease, let alone artistry with a musical instrument. Thus it was strange in a sense that throughout my career as principal trumpet to the CAPAB orchestra at the Nico Malan Theatre Centre, I found myself and my colleagues voicing numerous frustrations, misunderstandings and complaints. It was difficult to comprehend why our working environment, the orchestra pit, seemed to discourage rather than inspire our desire to perform with vital passion. Cramped conditions, poor acoustics and an unpleasant environment are common features of orchestra pit design. How much worse must it have been in the past? My personal concern was, why do such environments still occur?

The first draft of this thesis placed all the blame on the designer and his consultants : it seemed inconceivable that anyone else could be held responsible. However, subsequent research has revealed that numerous other aspects needed to be considered before responsibility, let alone blame could be assigned.

Later drafts suggested that the reasons for these recurring problems were the direct result of circumstance. In other words, because one of the main purposes of the opera pit is to conceal the view of musicians without interfering with the projection of orchestral sound, the options for pit design appeared to be restricted, thus suggesting that the pit was ill-fated by its very nature. While this is true to a large degree, it is far from being the only basis upon which the success of a sub-stage environment ought to be judged.

Then another facet emerged: the musician's role. Are his views conveyed effectively to the designer via the orchestra manager? Can the musician distinguish between fundamental pit design principles and the right to a comfortable working environment? Is there agreement upon which aspects constitute successful design, and indeed, are musicians capable of arriving at any such agreement? These are a few of the questions that need to be answered if a true attempt at alleviating some of pit environment's problems is to be sought.

Throughout this thesis there are a number of references to the financial factor in opera house planning. Although the budget may not affect the fundamental aspects of design, discrepancies between the standard of public and employee amenities are evident. A local example in Cape Town demonstrates this point. In the Nico Malan opera pit, the orchestra's music stands date from the inauguration of the theatre centre, yet extensive renovations to and upgrading of the rest of the complex, for public benefit, has occurred several times since 1971. While this is an isolated example, it does illustrate a trend in lowering the priority of features of the workplace, i.e. the orchestra pit. The significance of the financial factor is noted throughout this work, and where necessary is given pride of place.

Before an orchestra pit is realised in masonry, wood and fabric, the image the designer conceives will not only be influenced by technical, but also by artistic specialists specifically appointed to help in this respect. Thus, the opportunity to correct existing problems in pit design ought to be presented and adequately reviewed. Yet unless a clear image of the function of the orchestra pit is apparent from the onset, difficulties are likely to arise during the post-inauguration period.

Changes in the orchestra or production manager's aspirations represent one of the greatest threats to the musicians' environment. Decisions to expand the production potential of a theatre are encouraged by past successes, yet such developments may not have been anticipated in the designer's original plans. The result will often lead to over-crowding in the pit : a state which may in turn lead to a deterioration in the musician's level of morale and his relationship to his working environment.

The nature of pit design is concealment, a condition which in itself diminishes the musician's self-image despite his vital role in theatre.[1] The pit musician is regarded as an accompanist to the action on stage. Lowering morale further by not providing the proper facilities for a comfortable environment will eventually impinge upon the quality of musical performance. This is especially true of the orchestra pit where a single production can run for over a month : such situations result in the musician becoming particularly aware of the shortcomings of his environment. In the same way, niggling discomfort might hinder the creativity of any other worker whose product requires unfettered innovation, originality, and liveliness.

Accumulating information about the orchestra pit proved to be one of the greater challenges of writing this work. Pits tend to be mentioned only in passing, and references are thus vague. Despite this daunting realisation it was only

---

1 Interview : Veronica Paeper, Director of CAPAB Ballet, March 1991. During this interview Miss Paeper stated that, in her opinion, ballet is 45% dance and 55% music.

when I began to talk with specialists that the reason for this emerged - the orchestra pit has never been, and cannot be, regarded as a separate entity. Each chapter demonstrates that it is impossible to analyse the principle features of pit design without relating them to the auditorium as a whole. Nevertheless, although the pit has many immutable characteristics, it is the application of these principles that justifies the need to consider this environment independently.

CHAPTER 1

A History of the Orchestra Pit

A HISTORY OF THE ORCHESTRA PIT

" A historical review of any theatre problem has never been, in my experience, a waste of time, if you want to understand as much as you can about that problem. Historical research as I see it is not a matter of dates and names, nor even of trying to bring alive a theatrical technique which is now dead and gone. It is instead, purely a matter of increasing one's knowledge of a job one is doing today, by finding out a little more (one can only find a little) of the tradition of one's predecessors as they did that job."[1]

1. THE CLASSICAL ATHENIAN THEATRE

The history of theatre dates from time immemorial. It is only from the fifth century B.C. that historians can begin to assemble the fragments which eventually took the form of the classical Athenian theatre.[2] In its original form, theatre comprised two basic elements; the "orchestra" and the theatron.

1.1 THE "ORCHESTRA"

The word "orchestra", translated from the Greek language

---

1. SOUTHERN Richard, "The History of Adaptable Theatres", Conference : The Association of British Theatre Technicians, Adaptable Theatres, Pindar, Scarborough, U.K., 1962, P. 13

2. ATHANASOPULOS Christos Giorgos, Contemporary Theatre Evolution and Design, John Wiley & Sons, New York, 1983, P. 13

means, "a dancing place".[1] It was upon this level area, at the foot of a hill, that the chorus gathered together to sing and dance. The earliest "orchestras" were influenced by the shape of the surrounding seats and terrace, and they often had a "slightly irregular rectilinear" form.[2] Two distinguishing features were apparent : the sacrificial platform and the thymele. The platform was positioned in the centre of the orchestra where the leader of the chorus, Choryphaeus, would perform. This platform was originally placed next to the sacrificial altar, the thymele, but it was later removed and re-emerged as the Greek stage. In its earliest form, Greek drama was purely religious in character, and for this reason the thymele was situated in a prime location.

It was only at the end of the fourth century B.C., when the theatre at Epidauros was completed, that the "orchestra" became circular in shape (fig. 1).

1.2 THE THEATRON

Greek theatre catered for the entire community, regardless

---

1. SADIE Stanley (Ed.), "Orchestra", The New Grove Dictionary of Music & Musicians, Macmillan Publishers Ltd., London, 1980, p. 679

2. GEBHARD Elizabeth, "The Form of the Orchestra in the Early Greek Theatre", Hesperia, Vol. 43, 1974, p. 440

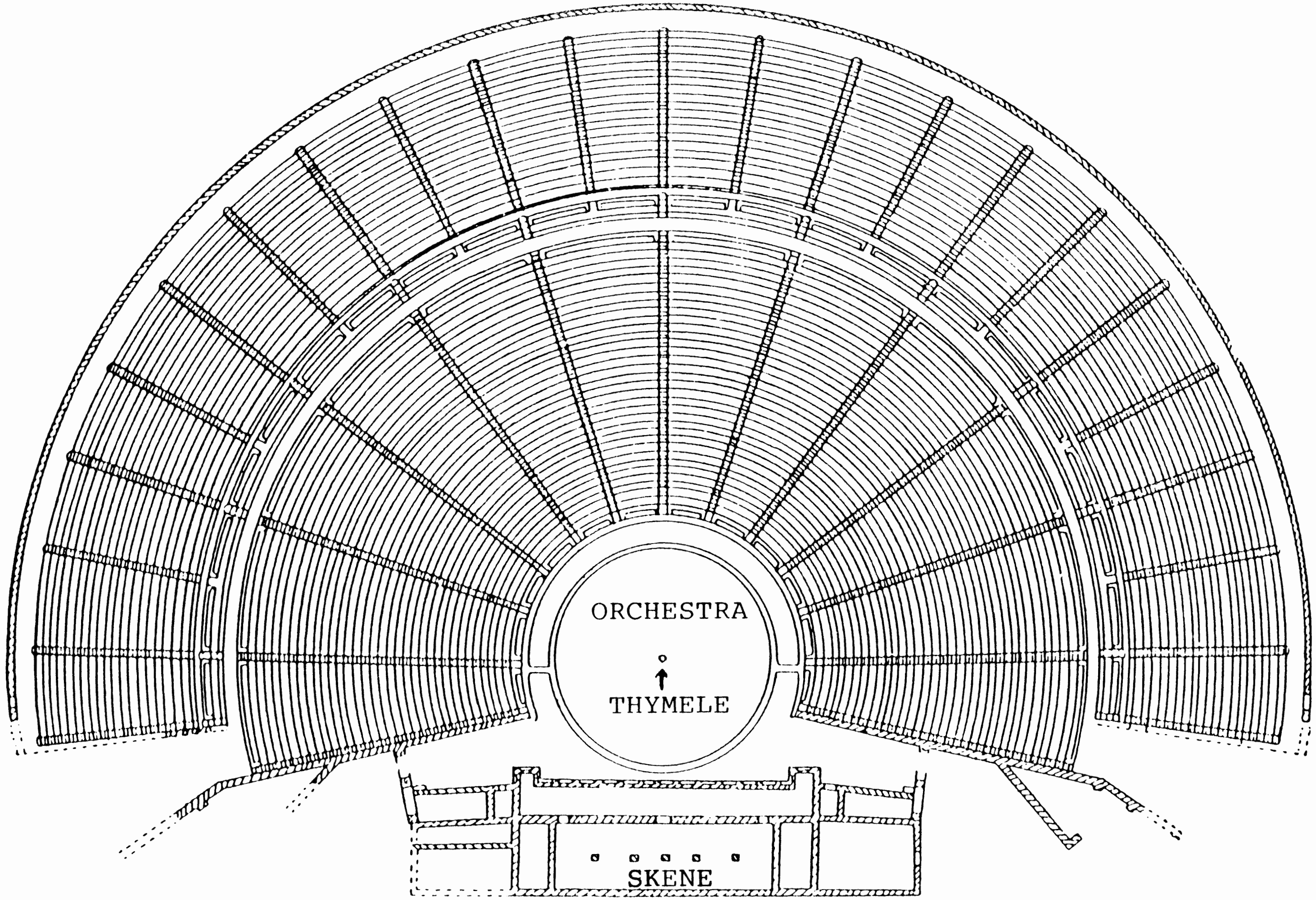


Fig. 1. Plan of the Theatre of Epidauros

Adapted from Nicoll P. 22

see following page,

(permission applied for)

of class, and it was not unusual for the audience to exceed fifteen thousand in number. Normally a large hill would be selected as the theatron, provided it had the attributes necessary for successful performance. Such a location had to offer two basic features: first, the physical shape of a hill had to enable each member of this huge audience to enjoy an uninterrupted view; second, the same attribute also should provide a unique acoustic.[1] The raked nature of a hill can offer an exceptionally fine acoustic - a feature modern theatre accepts as a prerequisite in acoustic design.

1.3 DEVELOPMENTS

As the theatre became more popular, the drama became less religious. Thespis introduced actors, thespians, and it was from then that the shape of the theatre began to develop. The actors now required a separate area for costume and mask changes. A wooden structure was erected for this purpose just on the edge of the "orchestra", changing it to a semi-circular shape. Eventually wooden seats, or ikria, were assembled along the remainder of the orchestra perimeter. These were reserved for members of the hierarchy and were

1. "Acoustic" as a substantive noun is a neologism, not accepted in the Oxford English Dictionary at present but, liberally used in such hallowed sources as The Grammophone, and is enshrined in current usage among musicians world-wide, who are after all, the prime users of the concept.

replaced later in the fifth century B.C. with rock tiers: "It was the collapse of the wooden seats at Athens in 499 B.C. which led to the erection of a stone auditorium theatre."[1] The sacrificial platform was moved to the back of the "orchestra", in front of the changing area. Initially only one actor took part in the drama, but in time the number grew, as did their needs and demands. The platform was enlarged and a proskenion was built between it and the changing booths, or skene.[2] As a result the "orchestra" became smaller in size.

Nevertheless it remained an important part of Greek drama. The chorus accompanied the action with different dance motifs which helped bridge the physical/visual gap between the theatron and the platform.

2. THE ROMAN THEATRE

Some centuries later the Roman theatre emerged. Many Greek characteristics were retained, but a number of changes did take place. This was as a direct result of the drama becoming more secular in nature - social and political

---

1. NICOLL Allardyce, The Development of the Theatre, 3rd ed., George G. Harrap & Company Ltd., London, 1948, P. 20

2. The proskenion was sometimes referred to as a part of the stage; at other times it signified the decorative wall in front of the skene.

problems began to feature in the plots. The altar was removed and the function of the "orchestra" changed. All performances now took place on stage, diminishing the importance of the "orchestra." The audience to actor relationship was thus improved in two ways: first, the proskenion and the skene were brought forward, closer to the audience. This resulted in the "orchestra" becoming semicircular in shape.(fig. 2) Secondly, extra seating was provided along the inner edge of the orchestra. These places were usually reserved for the use of senators. As a result of these modifications, the "orchestra" again became substantially smaller.

Other notable changes from the Greek theatre style included the paving of the "orchestra" and the introduction of a low wall around its edge. Occasionally the front row of seats were removed, giving the impression of a sunken "orchestra", as at the theatre at Miletus, Asia Minor. This feature, together with the raised stage, resembles the shape of the orchestra pit as we know it today.

Roman theatre had become enclosed within boundary walls and was built upon level ground, unlike its Greek counterpart. The first known example of a stone theatre in Rome was built by Pompey in fifty-five B.C. - the theatre had now become a permanent structure. Over the following centuries the basic

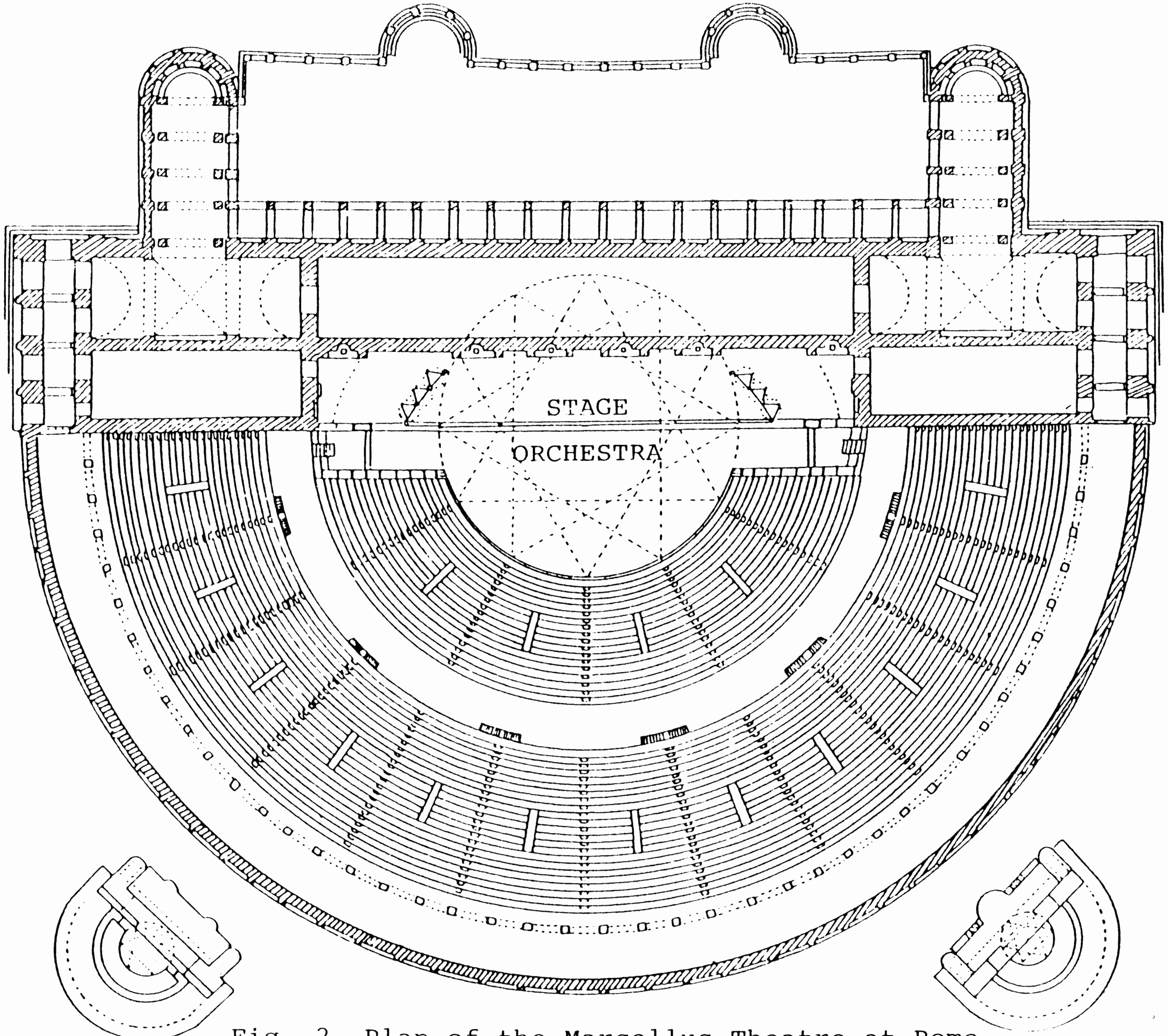


Fig. 2. Plan of the Marcellus Theatre at Rome

Adapted from Nicoll, P. 50

(permission applied for)

form did not change, except for the introduction of roofed theatres in mediaeval Europe. For the purpose of this study, the next significant development occured with the birth of the proscenium stage in the late 1500's.

3. THE PROSCENIUM STAGE

During the sixteenth century there was a renewed interest in Greek and Roman art and architecture. Renaissance architects researched Vitruvius' work on the subject of theatre design, thus facilitating their efforts to reconstruct theatres in the classical form. Perhaps the most important innovation at that time, which influenced the birth of the proscenium stage, was the introduction of perspective - a purely renaissance feature. At the time, perspectives of streets were by far the most widely used stage setting. Another development which was likely to have influenced the appearance of the proscenium stage was the "need to focus display towards a particular person or group of persons."[1]

The design and construction of the Teatro Olimpico (1580-4) at Vicenza, Italy, marked the "beginning of the proscenium theatre, which was to be the only kind of theatre for the

1. JOSEPH Stephen, Actor & Architect, Manchester University Press, U.K., 1964, P. 2

next three centuries."[1] Renaissance theatres were generally smaller than their classical counterparts, however the basic design compares favourably to that of the Roman theatre. Naturally, there was one significant difference - the Teatro Olimpico had been roofed, unlike the "open" Roman theatre. Other variations were also apparent: for example, the seating tiers were occasionally semi-elliptical in shape rather than semicircular, and it should be noted that the "orchestra" was sometimes at a sunken level (fig. 3). As in Roman theatre design, the "orchestra" was used for different functions : to provide extra seating or as an additional performance area for the actors.[2]

Notably, the first proscenium theatre in the form we know it today was not built until 1618. It was at Teatro Farnese in Parma, where behind the new arch 'frame', enclosed walls and scenery were three dimensional in effect rather than just in illusion. The later introduction of the curtain enabled quick scene changes and a greater variety of stage settings.

4. TEATRO SAN CASSIANO

In 1637, the world's first theatre specifically designed for

---

1. ATHANASOPULOS, P.60

2. LEACROFT Richard & Helen, Theatre and Playhouse, Methuen, New York, 1984, P. 47

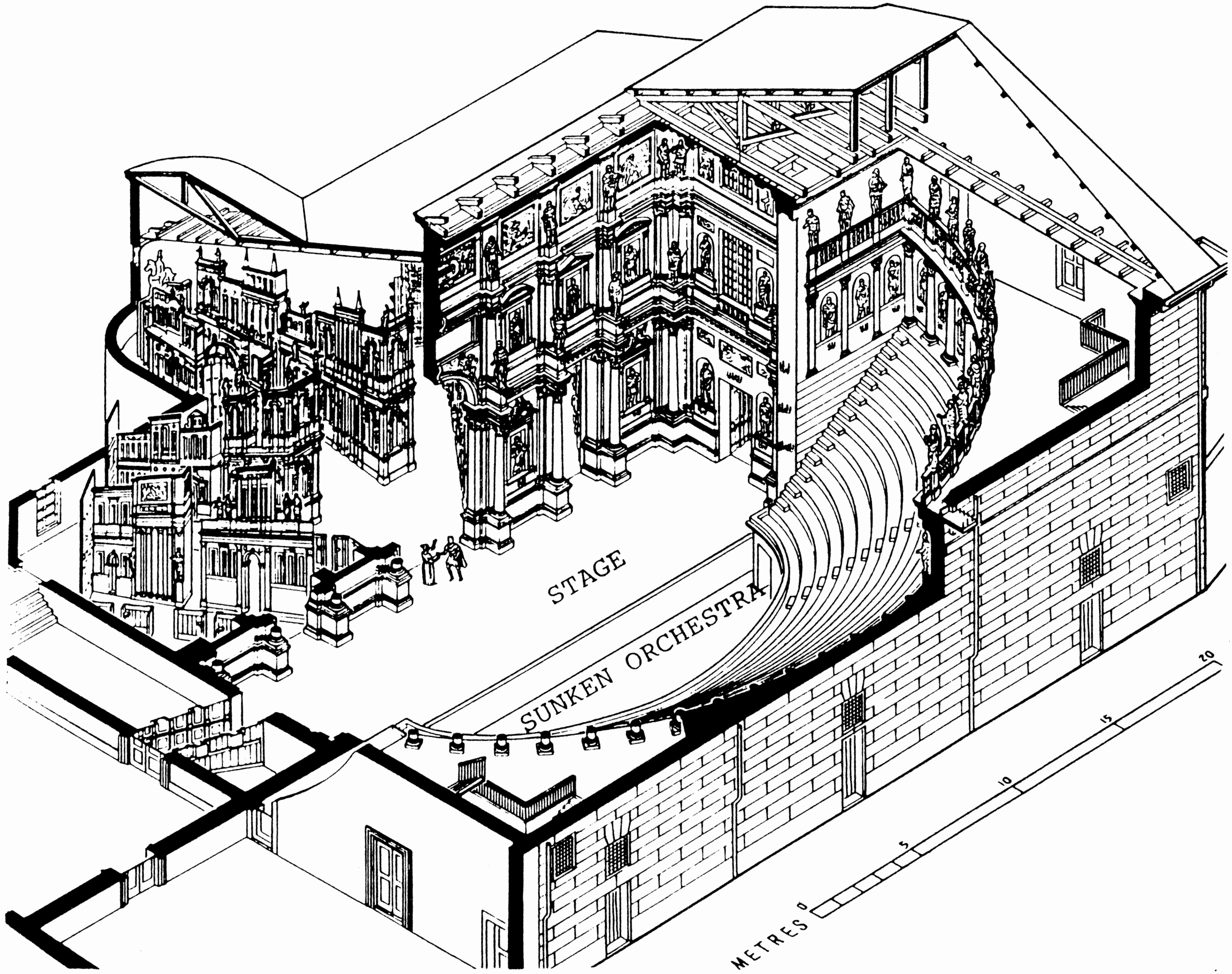


Fig. 3. Teatro Olimpico, Vicenza, Italy

Adapted from Leacroft, P. 45

(permission applied for)

opera was built in Venice - the Teatro San Cassiano. The opera L'Andromeda by Mannelli was written for its inauguration.[1] For the first time orchestral musicians were placed in front of the stage, unlike previous designs where they had been seated at the sides, in the galleries or behind the scenes.[2] It was from that date that the true history of the orchestra pit began. The function of the "orchestra" had changed - it was now solely for the use of musicians and was henceforth referred to as the orchestra pit.

5. EIGHTEENTH CENTURY ORCHESTRA PIT DESIGN

In many ways, the "open" orchestra pit of today does not differ greatly in design from the orchestra area at the Teatro Olimpico in Vicenza. However, several curious, even superstitious concepts were adopted in the years that lie between these periods. Acoustic problems were no less important then than they are now, and the question remained : how to achieve the correct orchestral balance from the orchestra pit? Many bizarre ideas were introduced. For example, the Teatro Regio in Turin (1740), is said to

---

1. LOEWENBERG Alfred, Annals of Opera 1597 - 1940, Societas Bibliographica, Geneva, 1955, P. 15

2. FORSYTH Michael, Buildings for Music, The MIT Press, Cambridge, Massachusetts, 1985, P. 76

have had " a semicylindrical trough below the wooden floor of the orchestra pit, made of masonry and running the entire length (fig. 4). Two tubes connected the ends of the trough with the stage. The intention was that the shape of the trough and its hard suface would reflect and reinforce the sound of the orchestra, while the air space was meant to assist the wooden floor to resonate."[1]

"Acoustic troughs" were a feature of many Italian orchestra pits at the time. Sometimes they were covered with an open grille or even extended under the audience. The Teatro Nuovo in Parma developed this idea further. Here, the entire area occupied by the audience was built over a masonry saucer connected to the pit by passages.

In France, the theatre at Besançon displays yet another interesting example of eighteenth century orchestra pit design. The theatre was completed in 1784 and the orchestra pit was built in the Italian style (fig. 5), The most unusual feature of the design is the semicylindrical wall at the back of the sunken pit. No doubt this acted as a reflector, further enhancing the function of the "acoustic

---

1. FORSYTH, P. 95

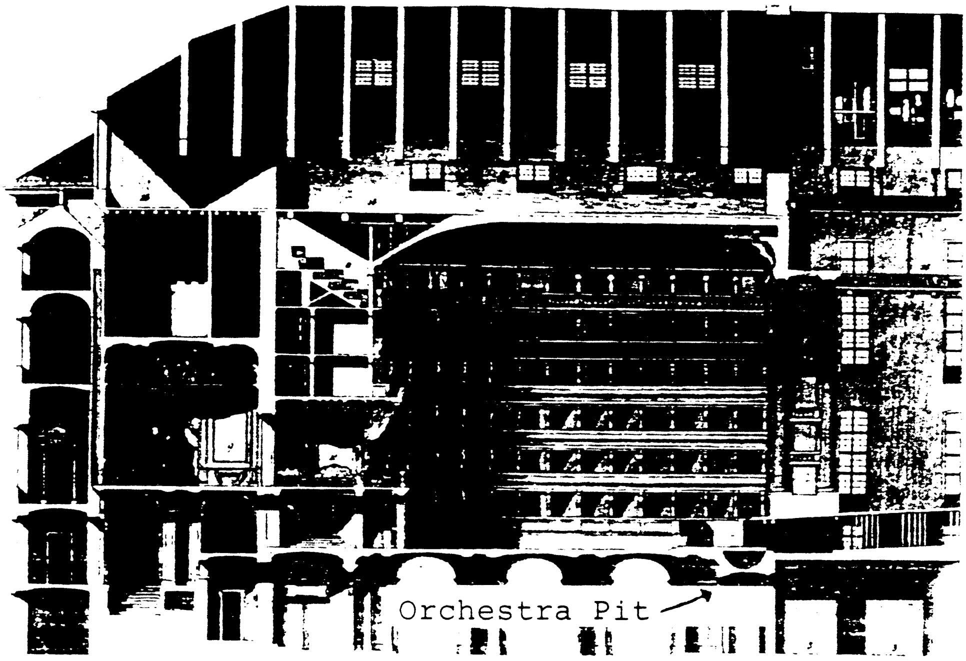


Fig. 4. Teatro Regio, Turin

Adapted from Leacroft, P. 82
(permission applied for)

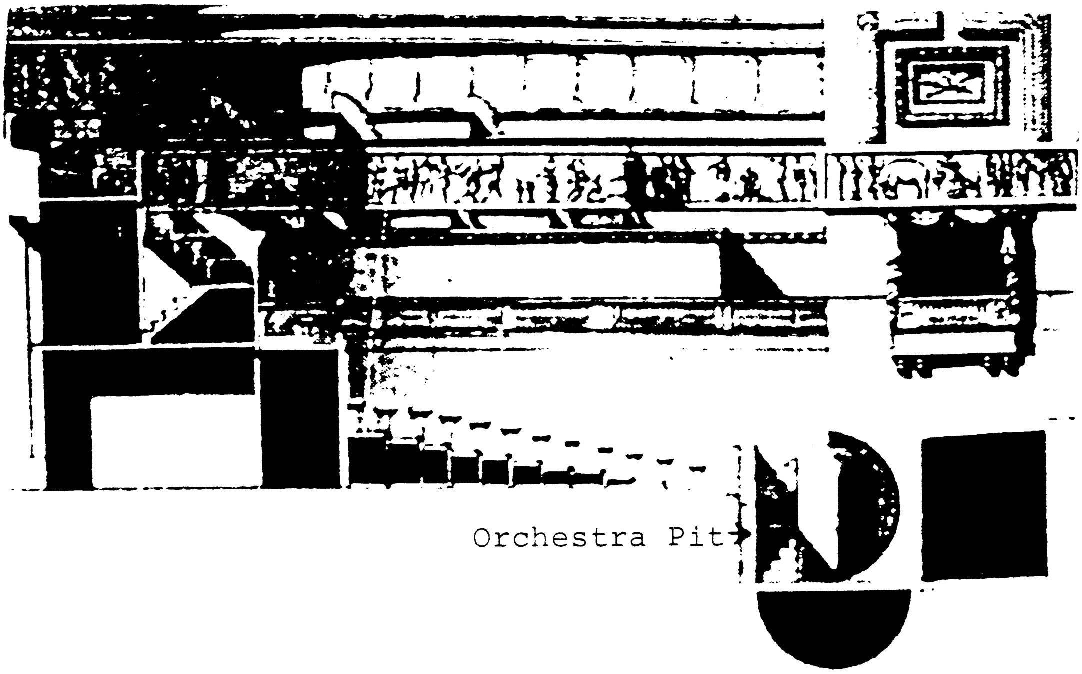


Fig. 5. The orchestra pit at the theatre at Besançon

Adapted from Forsyth, P. 113
(Permission applied for)

trough" underneath.[1]

In England, the Theatre Royal, Drury Lane, underwent a thorough redesign and restoration (1775). This included the construction of an orchestra pit for the musicians who had previously played from the side of the stage. In 1791, Covent Garden adapted its orchestra pit to the Italian style - building it over a trough "to assist general sound".[2]

6. NINETEENTH CENTURY ORCHESTRA PITS

Two major developments occurred during the nineteenth century, both of which had a tremendous impact upon the design of the orchestra pit. Fundamental changes in instrument design, which began during the middle of the previous century, culminated in a richer, more versatile orchestral sound. The other important feature was that the nineteenth century marked the beginning of the romantic era. Composers indulged in the use of far greater numbers of musicians for their compositions : Wagner often called for well over a hundred musicians. For these reasons, it follows

---

1. At the time, the use of such devices was said to have contributed greatly to the overall acoustic effect of the theatre. However, our knowledge of acoustics has improved dramatically over the past century. It is now scientifically possible to measure and assess the value of such pit designs.

2. LEACROFT, P. 82

trough" underneath.[1]

In England, the Theatre Royal, Drury Lane, underwent a thorough redesign and restoration (1775). This included the construction of an orchestra pit for the musicians who had previously played from the side of the stage. In 1791, Covent Garden adapted its orchestra pit to the Italian style - building it over a trough "to assist general sound".[2]

6. NINETEENTH CENTURY ORCHESTRA PITS

Two major developments occurred during the nineteenth century, both of which had a tremendous impact upon the design of the orchestra pit. Fundamental changes in instrument design, which began during the middle of the previous century, culminated in a richer, more versatile orchestral sound. The other important feature was that the nineteenth century marked the beginning of the romantic era. Composers indulged in the use of far greater numbers of musicians for their compositions : Wagner often called for well over a hundred musicians. For these reasons, it follows

---

1. At the time, the use of such devices was said to have contributed greatly to the overall acoustic effect of the theatre. However, our knowledge of acoustics has improved dramatically over the past century. It is now scientifically possible to measure and assess the value of such pit designs.

2. LEACROFT, P. 82

logically that the orchestra pit was destined to find a new form to cope with this new expanded size and greater orchestral projection.

7. WAGNER'S INFLUENCE

Nineteenth century Italian theatre design had become dull and repetitious. For the Italians, opera was a form of social entertainment, but for Wagner it had to be a broader musical experience. He was poised to revolutionise German theatre design and change the face of opera by referring to it as "music drama".

In 1876, after many years of attempting to create his own opera house, Wagner's ambitions were finally realised. "The Festspielhaus in Bayreuth is probably the world's most unusual opera house. Its design is unique : it was conceived by the composer Richard Wagner to satisfy his own image of how an opera house should look and sound and it responds well only to the music of its master ..."[1]

7.1 THE FESTSPIELHAUS ORCHESTRA PIT

The orchestra pit at Bayreuth has always been the source of

1. BERANEK Leo L., Music, Acoustics, & Architecture, John Wiley & Sons Inc., New York, 1962, P. 243

much controversy. It has firmly established itself as a major milestone in the history of pit design, as a result of the many unusual features that were adopted.

Perhaps the most notable characteristic is the sunken and concealed design of the pit. Visual concealment of the musicians was one of the features Wagner used intentionally in order to heighten the dramatic effect of his opera. He regarded them as distractions to the action on stage. Their job was to perform the music; they did not need to be seen.

Wagner first wrote of his desire for an invisible sunken pit in 1862 in the preface of the first edition of the Ring des Nibelungen. Although the orchestra pit at Bayreuth was the first of its kind to be constructed in the history of theatre, the idea was not an original one. As early as 1797, Gretry designed a similar pit where the musicians were hidden from the view of the audience.[1] This was to be achieved by erecting a stone wall between the pit and the auditorium. However, the plans were never realised. In 1821, the national theatre, the Schauspielhaus am Gendarmenmarkt in Berlin was completed. It is said to have anticipated Wagner's Festspielhaus because it made use of a sunken

1. GRETRY André, Memoirs ou Essais sur la musique, iii, no publisher, Paris, 1789, P. 32

orchestra pit for dramatic effect. [1] However, the use of several other original attributes give the orchestra pit at the Festspielhaus its unique character.

Up to one hundred and thirty musicians can be accommodated at Bayreuth - a revolutionary number, even by today's standards. Moreover, what is especially unusual is the fact that the audience hears no direct sound from the orchestra. This has been achieved by projecting the sunken pit under the forestage area and covering the conductor and strings with a solid wooden cover (fig. 6). The result is that the sound emerging from the pit is entirely reflected. The presence of the wooden cover gives the strings a somewhat muffled tone which is distinctly lacking in the higher frequencies.[2] Such characteristics in sound are not desirable for non-Wagnerian opera. A Mozart opera requires clarity and brilliance, a performance of which would be disastrous in such a hall, as would any Italian opera.

During the 1960's various experiments were carried out by Wieland and Wolfgang Wagner. Their objective was to create an orchestral blend with more brightness in the sound, without interfering with the effect of having the musicians

---

1. FORSYTH, P. 115

2. See ch. 3, para. 4.6

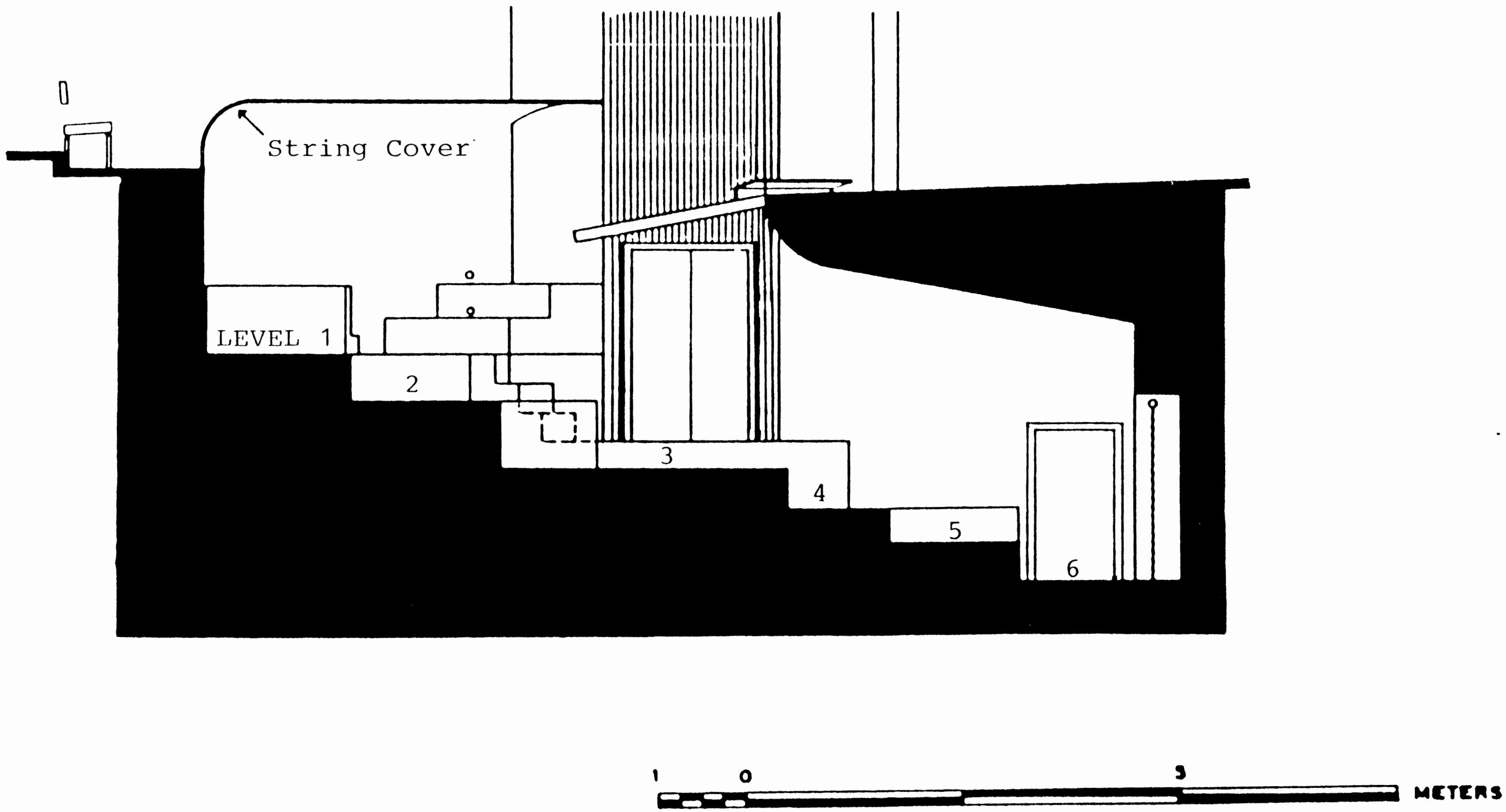


Fig. 6. The Festpielhaus orchestra pit, Bayreuth

Adapted from Beranek, P. 247

(permission applied for)

hidden from the audience. This was done by installing perforated shields in place of some of the wooden covers above the strings. Such perforations would allow a greater quantum of high frequencies to penetrate the auditorium. However, after the new shields were introduced, objections were raised by one of the conductors and consequently the old boards were replaced.[1]

Another interesting feature at Bayreuth was the various sectional platforms, six in all, descending as the pit projected further back under the forestage.(fig. 6) Upon each of these levels different sections of the orchestra would assemble, for example, the brass would be on the bottom level, right at the back of the pit. This design offered many acoustical advantages - the brass were kept under control and would not overpower the rest of the orchestra as is often the case. Such a design became less feasible with the introduction of modern stage equipment where it becomes impractical to go so far under the stage.

7.2 INFLUENTIAL CHARACTERISTICS

What makes the orchestra pit design at the Festspielhaus unique is the fact that only the romantic repertoire can be

---

1. BERANEK, P. 248-9

performed with any real measure of success. For Wagnerian opera it was ideal, representing what Wagner termed "a mystical abyss". However, despite its limited use, the Festspielhaus did influence the future design of orchestra pits. While the acoustic effect of the pit was extreme, one feature that has been a positive contribution to pit design was the extension of the pit under the forestage. This idea became the norm in orchestra pit design with few exceptions. Not only did this design facilitate economical use of space, but it also contributed to the acoustics of the theatre.[1]

8. A DIFFERENT APPROACH

In 1869, only seven years before the Festspielhaus was built, the original Staatsoper in Vienna was completed. It is probably the best example one can find of a non-Wagnerian approach to orchestra pit design. The top floor of the pit is a mere seventy-six centimetres below the house floor at the front. (fig. 7) Furthermore, little attempt has been made to hide the musicians from the view of the audience - it is an open pit. Obviously the effect is far removed from the "mystical abyss" Wagner succeeded in creating. In fact Viennese opera-goers often complain that the orchestra overpowers the voices on stage.

---

1. See ch. 3, para. 2

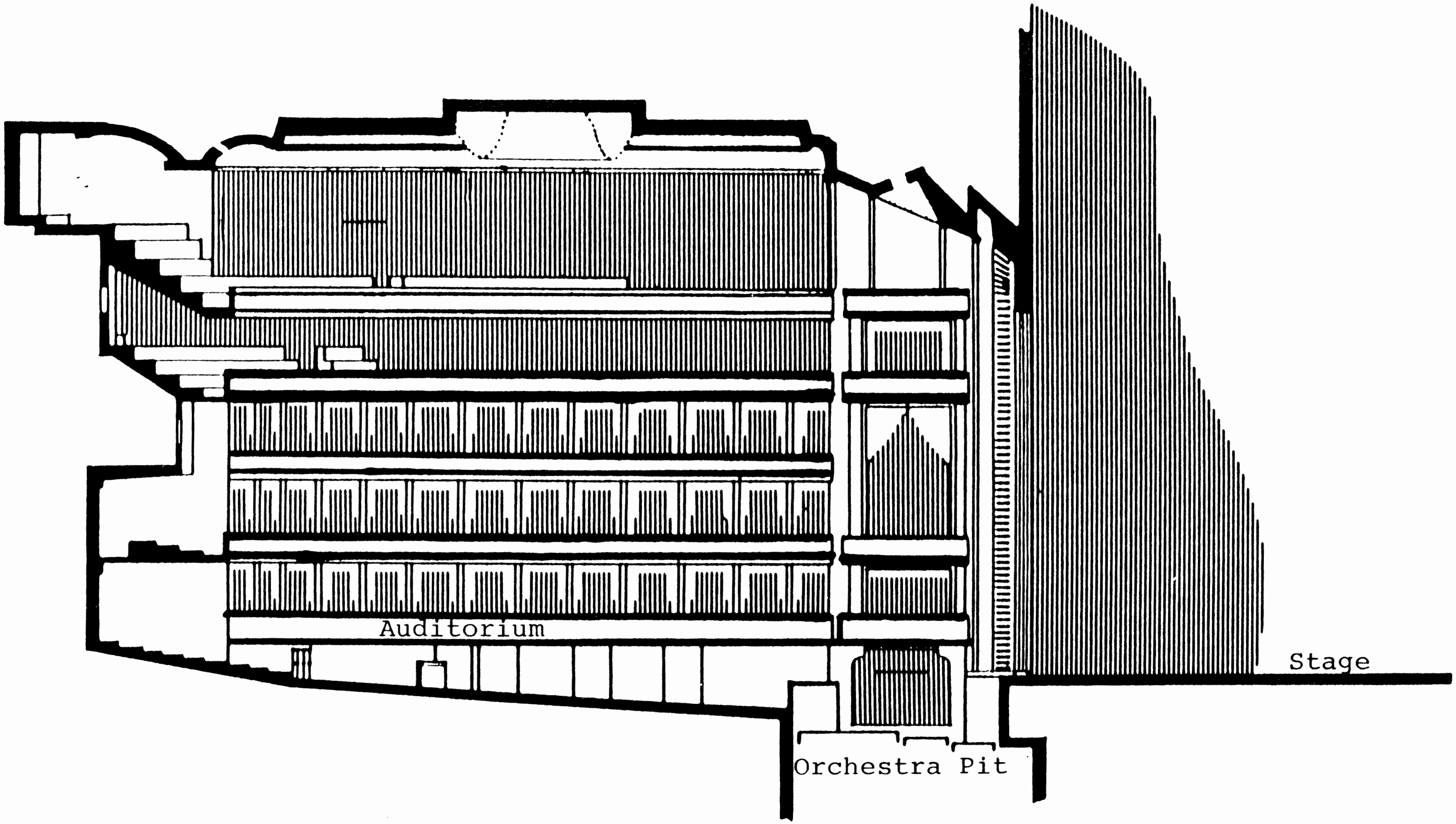


Fig. 7. Plan of the Staatsoper, Vienna

Adapted from Beranek, P. 201
(permission applied for)

9. ACOUSTICS - THE SCIENCE

With the exception of Wagner's detailed planning at Bayreuth, minimal attention had been given to the acoustic design of orchestra pits in the past. Indeed, even Wagner's motives have been questioned : Michael Forsyth writes "according to all that Wagner published on the sunken pit the main purpose was visual concealment, it has the secondary effect of subduing the loudness and altering the timbre of the orchestra".[1]

Just before the turn of the century, the first scientific discovery was made in the field of acoustics.[2] This marked the beginning of an entirely different approach. Scientific analysis would soon dictate many of the necessary prerequisites for the successful acoustic design of a theatre. However, it was not until the second half of this century that many preconceived notions had finally been rejected. For example, as late as 1907 the orchestra pit at La Scala was rebuilt along the same lines as the one in the Teatro Regio in Turin (1740). The wooden floor of the pit was built over a concave channel, the idea being to improve the acoustics (fig. 4). The effect was probably no more

---

1. FORSYTH, P. 192

2. See ch. 3, para. 1 : Reverberation time

beneficial than the acoustic mythology supporting the notion that broken wine bottles found inside the construction of European halls were strategically positioned to improve the acoustics. Only recently has the art of successful acoustic design been properly considered. Even so, our knowledge remains imperfect.

10. SUMMARY

The orchestra pit as we know it today was not officially introduced until the Teatro San Cassiano was built in 1637 in Venice, but it is important to understand how its basic position has been shaped during the past twenty-five centuries. Our first verifiable knowledge of the "orchestra" comes from the fifth century B.C. when it functioned as a singing and dancing area. Later, during the Roman period, the introduction of the stage gave the "orchestra" a secondary function. This fact was further emphasised with the birth of the proscenium stage in the renaissance period. It was only in the seventeenth century that the orchestra pit won itself a permanent position in the theatre solely for the performance of music. The basic shape and form of the pit have been established; it is now appropriate to examine the contemporary theatre design approach.

CHAPTER 2

Orchestra Pit Design

ORCHESTRA PIT DESIGN

Two of the fundamental factors which influence the ultimate design of the orchestra pit environment are addressed in this chapter.

The first emanates from the relationship between the stage, the auditorium and the location of the orchestra. This is referred to as the *contact factor*. Contact refers not only to the visual and aural aspect, but also to the emotional or psychological element : i.e. perception mediated by the brain.

The second, the *limitation factor*, is a corollary of the first : physical, acoustical, financial, personal and regulational circumstance are among those limitations which directly affect the designer's ideal image of the orchestra pit environment. Some of the more important facets of these limitations are reviewed.

Although a separate section of this thesis is devoted entirely to orchestra pit acoustics, references to the aural significance of certain design features are unavoidable - quality of sound must be given pride of place. Finally, a historical overview of the Nico Malan Opera House pit as built and subsequently modified serves to illustrate the application of fundamental design principles.

1. LOCATING THE ORCHESTRA

Two relationships dictate basic criteria for choosing the location of the orchestra.

A) In a theatrical context, the orchestra's contribution to a performance is usually purely aural. Consequently, throughout history emphasis has been upon concealing the musicians to a greater or lesser degree. In this way a deeper and more direct psychological bond is created between the stage performer and the audience.

B) Co-ordination of orchestral accompaniment with one or more performers on stage demands great competence in a complex conducting technique, where quality and clarity of contact is crucial.

The conductor and audience require optimum contact with the stage and vice versa - a precondition which limits the options for locating the orchestra. Some designers have endeavoured to utilise more modern approaches in an attempt to escape these restrictions.

2. EXPLORING THE ALTERNATIVES

The conventional position of the orchestra pit is between the stage and the auditorium. Although numerous attempts have been made to try to relocate the orchestra, no single design has established itself as an acceptable alernative to the orthodox position. Typical examples of alternatives are :

2.1 LOCATING THE ORCHESTRA ABOVE THE STAGE

In 1957, the Festival Theatre in Stratford, Ontario was designed with an orchestra gallery above the rear stage wall, "hidden from the audience but open to a circular sound reflector above the stage" (fig. 1). [1] This design is quite suitable for the performance of incidental music. However, productions dependent upon precise co-ordination between the stage and the orchestra suffer visual and aural constraints.

2.2 LOCATING THE ORCHESTRA ABOVE THE STAGE/AUDITORIUM

Barrie Greenbie, with the assistance of Elizabeth Harris, adopted a different approach for their dance theatre design :

---

1. LEACROFT, P. 178

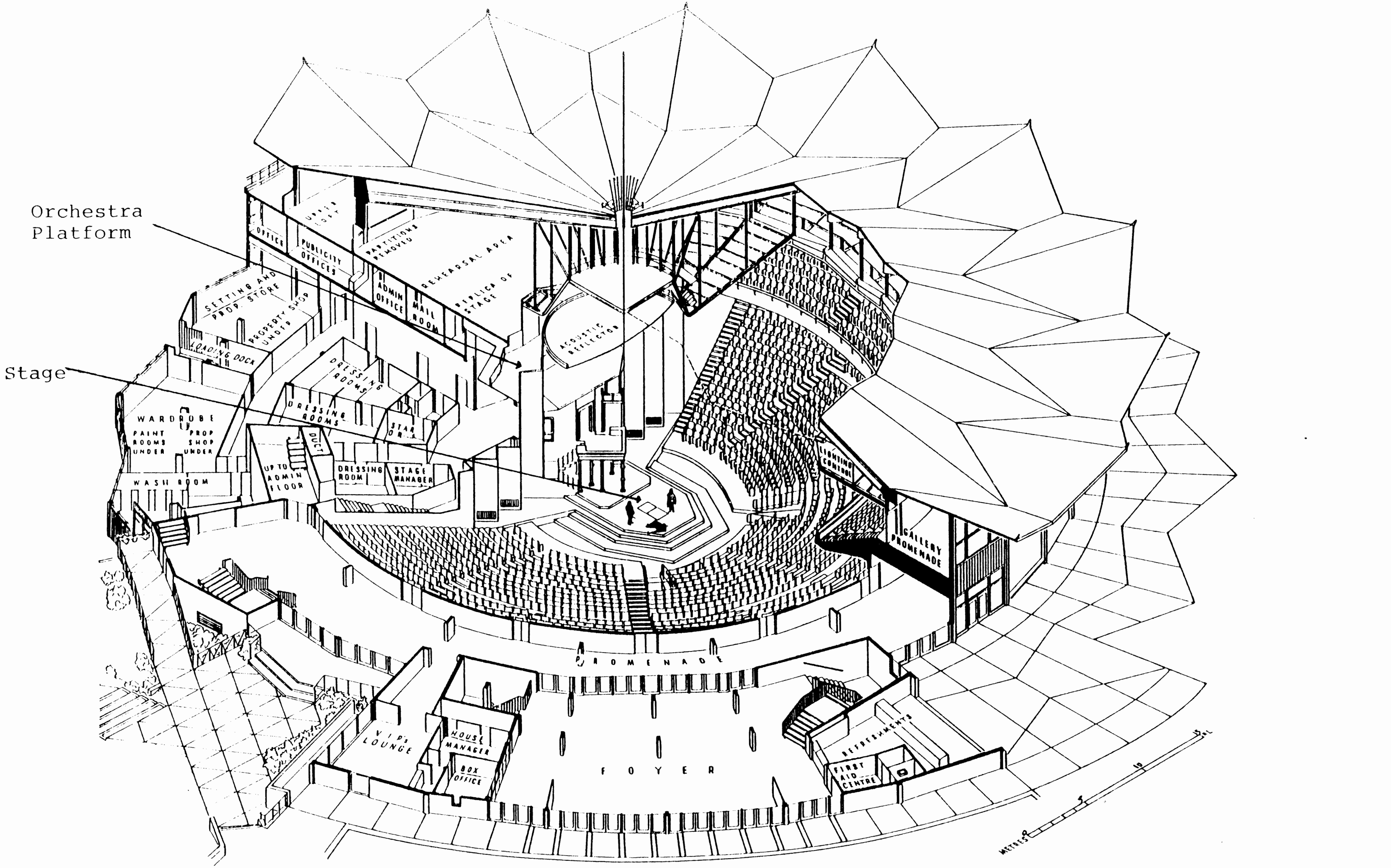


Fig. 1. The Festival Theatre, Stratford, Ontario, 1957

Adapted from Leacroft, P. 176

(permission applied for)

> "As noted, an orchestra may be located in the more conventional position... A permanent orchestra platform, however, is provided in a unique location above the stage, with an open floor grating masked by an acoustically transparent ceiling baffle. An acoustical shell above it will direct the sound down into the auditorium, originating at a point equally distant from audience and performers, positively eliminating any danger of discrepancy between what the audience sees and hears, which may be a problem when there is too long a reverberation time. It also makes possible direct live music without the visual competition of orchestra and conductor. Under this arrangement the conductor will watch the performance on a small television screen located on his podium. When it is desired to integrate a singing chorus with the dance, as Elizabeth Harris has done, the performers may if necessary, see the conductor on a closed circuit television screen at various points under the stage ramps. ..." (fig. 2) [1]

Although never realised, this design does raise some interesting matters of contention. Harris' involvement suggests that the contact factor between the conductor and performer may not be as vital as first envisaged if the two can be successfully separated using one or more television monitors. Whether or not television monitors are an effective substitute for eye-to-eye contact is another matter. One disadvantage is that cameras do not provide the three dimensional movement necessary for cueing, an

---

1. GREENBIE Barrie, (in) The Ideal Theatre : Eight Concepts, American Federation of Arts, Tri Arts Press Inc., New York, 1962, P. 50

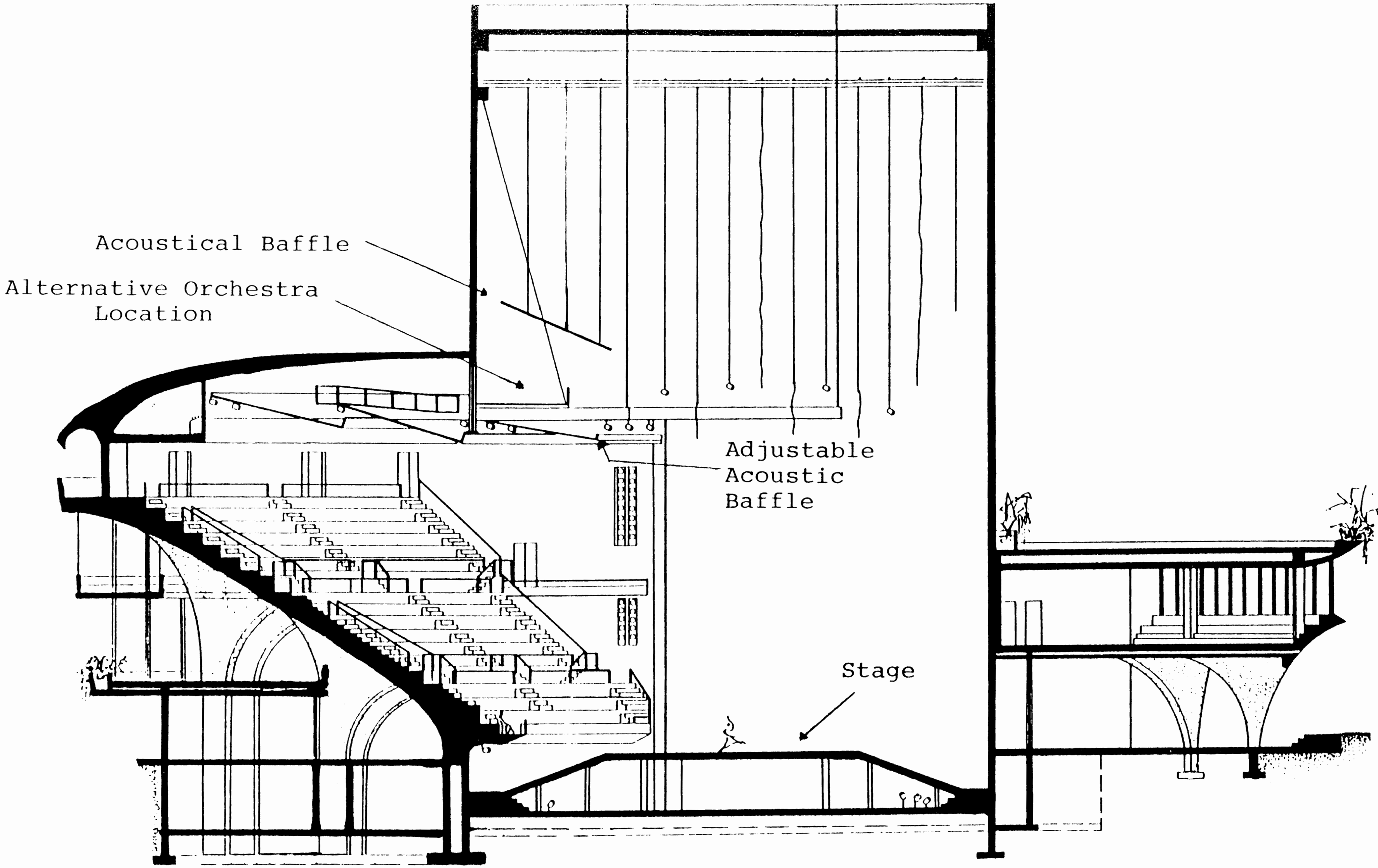


Fig. 2. A Theatre for Dance. Designed by Barrie Greenbie, 1962

Adapted from Greenbie, P. 51

(permission applied for)

essential feature of communication in conducting.[1] Furthermore, it seems likely that the level of emotional contact between the conductor and performer is significantly affected. One of the peculiarities of the psychological relationship between conductor and performer is the charisma and temperament of the conductor: the performance can be said to hinge on it, and any muting or distancing of this factor place the artistic integrity of the performance at risk.

2.3 RELOCATING THE ORCHESTRA

Sarah Caldwell explored the possibilities for completely removing the orchestra from the theatre with the use of dual-direction electronic and video links.[2] The difficulties associated with this type of design are similar, although more exaggerated than the latter innovation. By placing the orchestra in a separate room, the "living" element of music disappears, and in turn the atmosphere is impaired - no electronic public address system fully replicates or transmits the sound of an orchestra at our present stage of technology.

---

1. One speculates that holographic technology may in the future solve most of this problem, with an accurate three dimensional representation of the conductor either close to stage or close to orchestra.

2. JOHNSON Russell, "Orchestra Pits", Theatre Design & Technology, Massachusetts, Vol. 15, No. 3, Fall 1979, P. 14

2.4 REMODELING THE CONVENTIONAL PIT LOCATION

In 1992, Michael Bennett, the producer of the musical show Chorusline at the Nico Malan Opera House, adopted an interesting combination of both Caldwell's and Wagner's objectives. For each performance the orchestra pit was completely covered with a black sound-transparent material allowing minimal spillage of light. The musicians are concealed from the audience, yet their presence is perceived. Dual-direction video links are required for communication between the pit and stage, and the orchestral projection is boosted using sound equipment.

3. THE BASIS OF THEATRE

Despite modern attempts to break free from the restrictions of the conventional pit location, once the conductor-to-performer or audience-to-stage relationships are compromised, the very basis of theatre is threatened. It is therefore evident why the traditional position of the pit has remained so constant throughout history.

4. THE "PSYCHOLOGICAL GAP"

The distance between the audience/conductor and the performer is frequently referred to as the "psychological gap". There is a direct relationship between distance and quality of contact. Some designers are of the opinion that this "relationship is the starting point round which the planning of a theatre evolves".[1] In conventional theatre design, the contact factor is improved by reducing the depth of the orchestra gap to a minimum (i.e. the surface area between the pit front wall and the forestage). Calculating the most appropriate depth depends upon the limitation factor.

5. THE ORCHESTRA GAP

Perhaps the most important reason for the existence of the orchestra gap is acoustics. Depending upon the depth of the gap, the acoustic potential of the theatre and the pit is substantially influenced.[2]

The next most significant reason stems from the conductor's involvement. His primary duty is to unite the performance on stage with the performance in the pit. In order to achieve this, conductor contact (distances) between pit and stage are balanced against conductor sighting angles between the

---

1. HAM Roderick, Theatre Planning, The Architectural Press, London, 1972, P. 61

2. Ch. 3, Para. 2 : Coupling factor

same two areas as well as to the music score. In other words, if the pit front wall is too far from the forestage then the contact factor is poor. Similarly, if the gap is too narrow, then the conductor's angle of vision is uncomfortably wide, and his views of the stage and pit are not in full perspective.

Finally, modern theatre expects the accommodation of a hundred or more musicians in the orchestra pit. The size and seating layout of the performing orchestra also directly affect the gap depth.[1]

Considering that the above limiting factors are assessed jointly, the possibility for finding an all-embracing remedy becomes less remote. In essence however, the main challenge emerges from the conflict between the required floor area and the desired orchestra gap depth. One solution is to extend the orchestra floor beneath the stage, creating an overhang and thereby reducing the distance between the conductor and stage performer.[2] Despite the numerous advantages this design feature presents, several limiting factors also restrict the overhang depth. Before these

---

1. The orchestra seating plan for opera and ballet are interchangeable. See appendix 1, para. 6

2. Note : unless otherwise stated, any further reference to the overhang refers to this specific type (i.e. the forestage overhang).

aspects are outlined, it is necessary briefly to describe and define the fundamental design terminology associated with the conventional pit forms mentioned thus far.

6. ORCHESTRA PIT FORMS

Conventional designs are subdivided into two basic forms : the "open" and the "closed" pit. The former refers to those orchestra pits where the floor area is equal to the "open" area (i.e. between the front wall of the pit and the forestage). Designs that alter this relationship with the inclusion of an overhang are referred to as closed pits. The latter designs are possible only when the pit floor is constructed below the house floor level, hence the term "sunken" pits.

The Staatsoper in Vienna is an example of an open, non-sunken pit (see ch.1, fig.7). There are very few advantages associated with this type of design. The contact factor is seriously affected by the shallow pit floor levels - exposed musicians obstruct the audience's view. These high floors do have some acoustic benefits but the advantages are limited and will be discussed in the following chapter.

The Festspielhaus in Bayreuth represents the other extreme of orchestra pit design (see ch.1, fig.6). The contact factor for the audience is good because the overhang, string cover and sunken floors ensure that the musicians are totally concealed ("a mystical abyss"). Acoustically, the benefits of this design will be shown to be equally limited.

The above examples represent the extremes of orchestra pit form. Each pit has its own specific function or purpose. Their limitations clearly emphasise the need to balance both design types when adopting the versatile approach required of a modern general-purpose theatre.

7. THE ADVANTAGES OF THE PIT OVERHANG

These are some of the advantages that result when the overhang is used as a fundamental feature of the pit design :

A) The depth of the "psychological gap" is reduced, thereby improving aspects of the contact factor.

B) The musicians are mostly concealed - visual contact is ameliorated both for conductor and for audience.

C) Depending upon the depth of the overhang, the acoustics of the orchestra pit are directly affected. A change in the pit acoustics results in a change to the opera house acoustics. The open and largely closed pits have a repertoire that is not only limited but opposed in style and content.

D) Without the use of an overhang for large-scale productions, either the contact factor or the size and seating layout of the orchestra will be adversely affected, depending upon the balance of aims and purposes.

7.1 LIMITING FACTORS GOVERNING THE OVERHANG DEPTH

The stage lifts and the prompt box limit the depth of the forestage overhang :

A) By installing the stage lifts as close to the audience as possible, maximum visual impact is created. The full potential of the equipment is then realised whenever the lifts are used for special effects.

B) The traditional position of the prompt box (i.e. between the back wall of the orchestra pit and the front of stage) creates a further constraint. Despite being a standard feature in Germany, the prompt box is generally omitted from modern designs. Some stages are small enough to prompt from the sides, others benefit from the use of electronic equipment. A highly directional loudspeaker is an effective means of prompting while remaining concealed from the audience.

Depending upon its depth, the overhang also presents the designer with certain dilemmas :

> "To the best of my knowledge, no existing pit that is in large part buried under a platform gives the orchestra the natural sound heard in the opera houses of Vienna, Milan, Paris or London."[1]
>
> "The trade-off here, of course, is that in return for improved acoustics - a much easier and a much more natural way to obtain sectional balance in the pit orchestra and greater sound level as heard in the audience area - he has had to give up some revenue."[2]

Theatre is managed as a business - this is a fundamental reality which influences certain aspects of pit design. Johnson suggests that where the capacity of the auditorium is given high priority, the designer may include an overhang in the pit design as a means of creating additional auditorium space. In this respect, business interests may interfere with artistic interests. However, considering that the pit is the source of the orchestral sound, it is improbable that a designer will risk detracting from the acoustics of the entire auditorium for the sake of an extra

1. BERANEK, P. 509

2. JOHNSON, P. 13

few seats. Other options, such as a balcony, provide a more realistic solution.

There is a direct relationship between the overhang depth and the anticipated orchestral repertoire. Despite the validity of Beranek's comment above, it is important to emphasise that the overhang can make a positive contribution to the acoustics of the theatre. The basis of this argument will be dealt with in more detail in the following chapter on orchestra pit acoustics.

One innovative and pertinent design feature adopted at the La Scala Opera House in Milan was the installation of a sliding forestage. The depth of the overhang ranges from approximately one metre to three and a half metres. The acoustics of the pit and surrounding auditorium can then be adjusted to suit the repertoire performed. This feature is suited only to orchestra pits without lifts, otherwise obstruction is likely to occur should the lifts be raised to forestage level.[1]

8. CALCULATING THE ORCHESTRA FLOOR AREA

Thus far, some of the critical advantages and limitations

---

1. See para. 10.3

associated with calculating the depth of the orchestra gap and the overhang have been described. But without knowledge of the total floor area required for an orchestra pit, there is no premise upon which to work. It is this stage of the design process that is fundamental to the success of the sub-stage environment. The following quote by Russell Johnson, "the world's leading acoustician", confirms this viewpoint[1] :

> "If the proper design approach is utilised, the conductors will no longer be faced with the problem of having to "make do" with a smaller orchestra than called for by the composer, will no longer have to accept cramped conditions for his musicians, and theatre / concert hall / opera house owners will no longer have to consider bringing jackhammers after opening day to make their opera pits large enough for their opera-producing organisations."[2]

The above quote suggests that the problem of underestimating the pit floor area is a common one. Why does this problem recur?

The theatre designer's ability to identify, and anticipate from the onset, the problems related to orchestra pit design is perhaps the most important step toward achieving success. In order to fulfill this requirement, a number of technical

---

1 RAMSEY Basil, "Editorial Jottings", The Musical Times, Vol. 132, No. 1778, April 1991, P. 170

2. JOHNSON, P. 12

and artistic consultants are usually selected to discuss and assess the challenges jointly.[1] When calculating the floor area, the designer relies upon the orchestra and production managers to provide a clear blueprint of the number of musicians that will occupy the pit and, of equal importance, the sectional seating plans for an opera and/or ballet orchestra. Once this requirement is met, two further aspects need consideration.

8.1 THE INDIVIDUAL MUSICIAN

Calculating the floor space required per musician is a facet of orchestra pit design worthy of extensive research. The following factors highlight the complexity of this task :

A) The scope of the intended repertoire needs to be established. For example, some productions may require the use of two sets of timpani or two grand pianos.

B) Each musician should be considered independently. Larger instruments, such as the trombone or double-bass require more playing room than, for example, the oboe. During prolonged tacet sections, the heavier instruments such as

---

1. Architects, acousticians, electrical and mechanical engineers, conductors, as well as orchestra and production managers are among the consultants that assist the designer.

and artistic consultants are usually selected to discuss and assess the challenges jointly.[1] When calculating the floor area, the designer relies upon the orchestra and production managers to provide a clear blueprint of the number of musicians that will occupy the pit and, of equal importance, the sectional seating plans for an opera and/or ballet orchestra. Once this requirement is met, two further aspects need consideration.

8.1 THE INDIVIDUAL MUSICIAN

Calculating the floor space required per musician is a facet of orchestra pit design worthy of extensive research. The following factors highlight the complexity of this task :

A) The scope of the intended repertoire needs to be established. For example, some productions may require the use of two sets of timpani or two grand pianos.

B) Each musician should be considered independently. Larger instruments, such as the trombone or double-bass require more playing room than, for example, the oboe. During prolonged tacet sections, the heavier instruments such as

---

1. Architects, acousticians, electrical and mechanical engineers, conductors, as well as orchestra and production managers are among the consultants that assist the designer.

the tuba are laid down beside the musician, as are accessories (mutes etc.). Other musicians frequently "double" on an additional instrument, sometimes requiring the use of a separate instrument stand, for example the contra-bassoon or bass clarinet. The conductor's podium, music stands and risers also need to be accounted for in the final plan.

8.2 THE ORCHESTRA SIZE

The designer should not base his calculations upon the resident orchestra size because this figure does not necessarily represent the number of musicians making frequent use of the pit. Employment of free-lance musicians is an attractive financial proposition for the orchestra manager, making possible the opportunity to increase the orchestra size for larger scale performances, or alternatively for the purpose of enriching the orchestral sound. The former ambition is encouraged by the success of previous productions. In return, a broader range of musical tastes is provided for and further acclaim is gained for the theatre. Consequently, it is important to establish the potential size rather than just the resident size of the orchestra.

8.3 Formulae.

> "You will often find guidelines published in various reference materials - recommendations that the size of an orchestra pit should be based on a certain number of square-feet-per-musician. Avoid using any of these "square-feet-per-musician" guidelines as they so frequently lead to inadequate pit design".[1]

Most formulae recommended by theatre designers are vague and approximate. For example, in an article in The Architects' Journal, a minimum floor space of 8 sq ft (0.74 M^2) per musician is suggested without further reference to any additional considerations.[2] Roderick Ham recommends 1 M^2 for the musicians and conductor, 5 M^2 for the piano and 5-6 M^2 for the timpani.[3] Percy Corry advises 10 sq ft (0.93 M^2) per player, 50 sq ft (4.65 M^2) for the piano "and about the same for the drummer's bulky collection of instruments".[4] On the basis of the considerations outlined above, these recommendations fall short in many respects. Therefore, formulae should only be used during the initial stages of design as a means of providing an approximate size for the pit. Even then, the figure must not be underestimated :

---

1. JOHNSON, P. 11

2. "Orchestra Pits", Information sheet 1267, The Architects' Journal (Information Library), Vol. 140, No. 4, 22 July 1964, 1 of 1

3. HAM, P. 61

4. CORRY Percy, Community Theatres, Pitman Publishing, London, 1974, P. 74

Beranek suggests that 17.75 sq ft of floor area (1.65 M^2) per musician is acceptable[1], while Johnson suggests 16 square-feet-per-musician (1.49 M^2)[2]. The most important point to remember is that each orchestra pit will be required to perform a specific, individual function. The endorsement of any one formula for the final plan is likely to result in a potentially inadequate design.

Once the required floor area is established, the depth of the orchestra and the overhang gaps are then calculable. The proportion of the two depths depends upon the limitation factors already described. Of these, the acoustic factor is the more important because sound production is central to the function of the orchestra pit environment.

9. HOW THESE FACTORS AFFECT OTHER DESIGN FEATURES

The orchestra lift, pit railing, props guard, entry/exit doors, fire curtain and storage areas are all features of the orchestra pit environment which are also directly influenced by either the contact or the limitation factor, or both. An individual account of the above design features not only facilitates an understanding of the extent to which

---

1. BERANEK, P. 508

2. JOHNSON, P. 12

each is affected by these factors, but also provides us with a basis for planning a successful pit environment.

10. ORCHESTRA LIFTS

Modern opera houses present a broad and varied range of productions. Certain performances require an augmented orchestra, others a chamber orchestra, and where the music has been recorded ahead of time, the pit will have no orchestral use. Should such a superfluous orchestra gap occur, the psychological gap becomes unnecessarily highlighted. To date, the installation of an orchestra lift is the most effective means of improving the contact factor and achieving pit floor adaptability. Initially, the installation of a lift or lifts is an expensive undertaking, but in the final analysis it proves to be a wise investment once labour cost savings have been taken into account. Depending upon their positioning, up to three lifts offer adequate flexibility for an orchestra pit. One problem with providing a greater number is "that their use may be very limited in relation to their cost."[1]

---

1. HAM, P. 85

10.1 THE ADVANTAGES OF USING TWO ORCHESTRA LIFTS

Two orchestra lifts, positioned parallel to the auditorium tiers, provide a combination of no less than five alternative possibilities for a flexible pit design. Each of these combinations ensures that the psychological gap is kept to a minimum whenever the pit function changes.

A) Where an extended stage is required, both lifts may be raised to the forestage level. This arrangement is particularly suited to large scale compositions. For example, Beethoven's Ninth Symphony requires an orchestra, soloists, and a choir (fig. 3).

B/C) Some productions do not require an orchestra. If both lifts are raised to house floor level, extra seating can be erected (fig. 4). This arrangement is also used for conferences. With the fire curtain down, contact between the speaker and audience is optimal.

By way of alternative, one lift can be used as an extended forestage and the other to provide extra seating (fig. 5).

D/E) Light or chamber opera requires a smaller orchestra where the use of a single lift is adequate. By raising the inner lift an extended forestage is created (fig. 6).

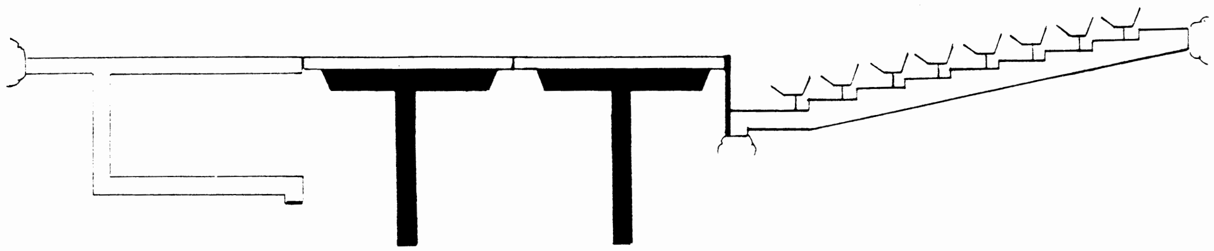


Fig. 3. Both lifts are raised to forestage level

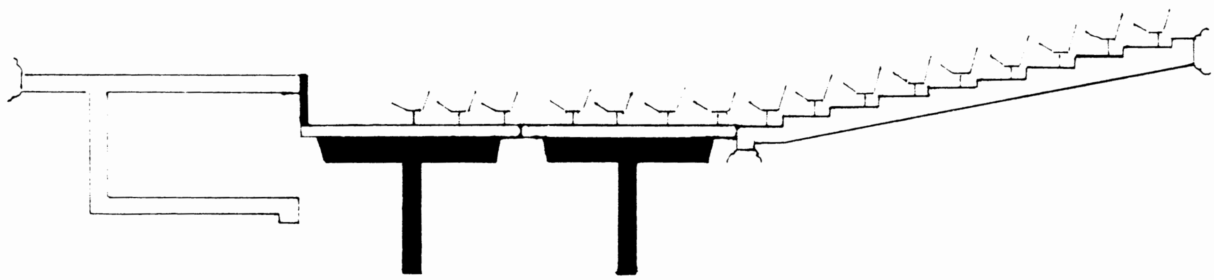


Fig. 4. Both lifts are raised to house-floor level

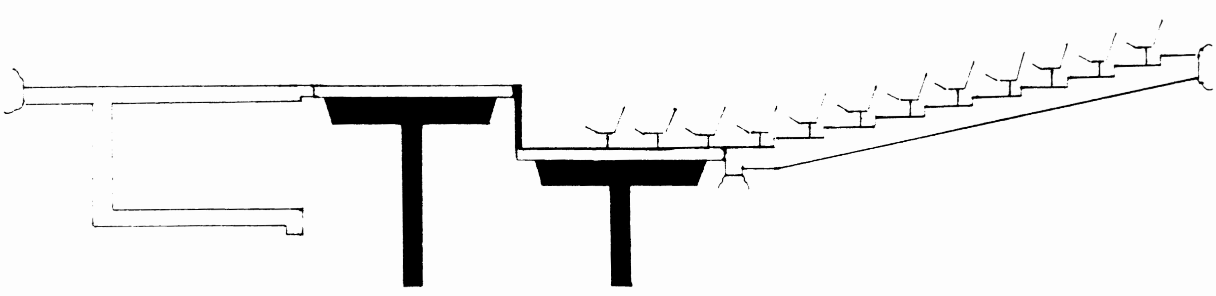


Fig. 5. The inner lift forms an extended forestage and the outer lift provides extra seating

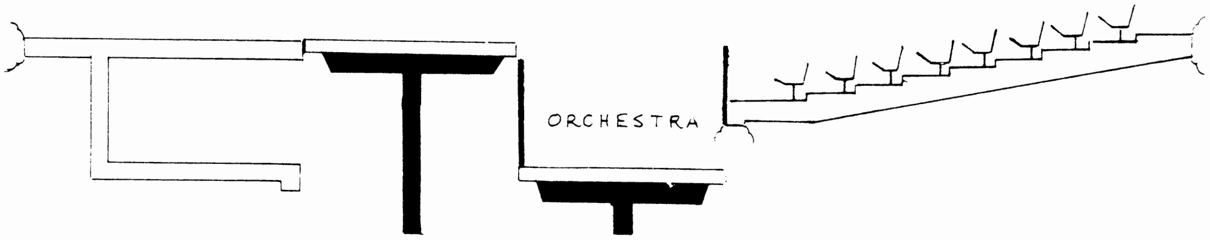


Fig. 6. The inner lift forms an extended forestage while the outer lift is used for a small orchestra

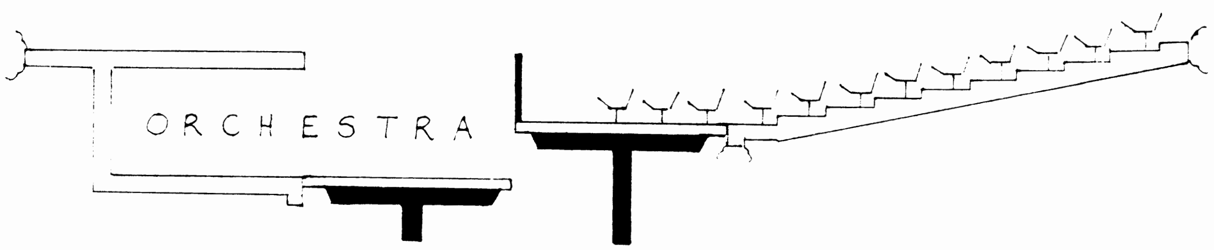


Fig. 7. The inner lift remains at orchestra-level while the outer lift is raised to house-floor level

Alternatively, if the outer lift is raised to house floor level the auditorium capacity is further increased (fig. 7).

10.2 DOUBLE LEVEL LIFTS

It would be impractical to explore all the possibilities of a flexible pit design emanating from the installation of mechanical lifts, however the benefits derived from utilising double level lifts merit special mention. One of the primary advantages identified with this type of design is the option to function simultaneously as an orchestra pit and as an extended forestage (fig. 8). While this arrangement undoubtedly represents an economic use of space, acoustic drawbacks may arise as a result of the extended overhang.

10.3 CALCULATING THE DIMENSIONS

The width of the orchestra lift should be no smaller than the proscenium opening if the use of an extended forestage is envisaged. In order to maximise the practicality of the lifts, their total depth must be equal to the open area of the pit - when the lifts are raised to forestage level, no orchestra gap should be apparent. The distance the lifts travel will depend upon the variety of functions they perform.

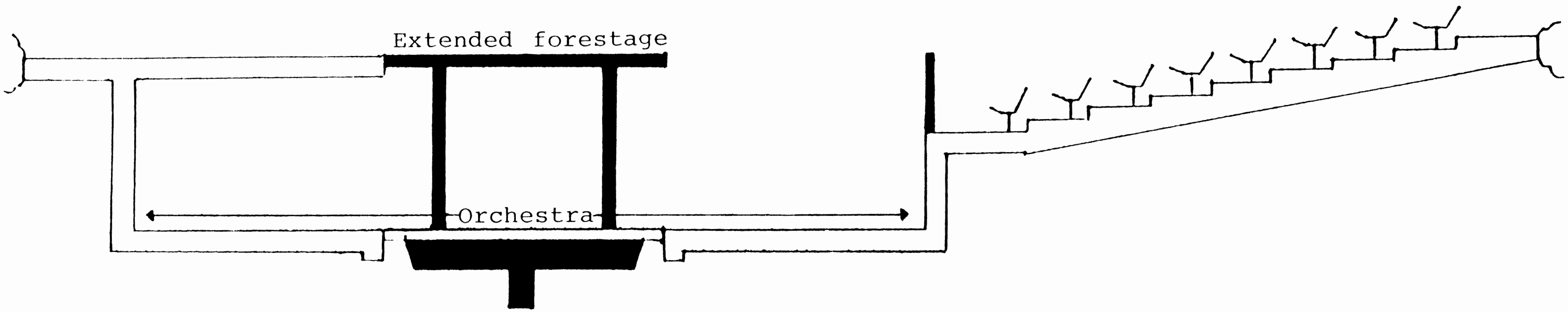


Fig. 8. A double level orchestra lift functioning as an orchestra pit and extended forestage

A clear-cut formula for calculating the lift dimensions cannot be recommended. Contrary to this opinion, some designers insist upon giving guidelines. Corry advises the use of two lifts "each ... about 1.9 M deep".[1] One would respond wondering whether the most appropriate depth for an orchestra gap is 3.8 meters, regardless of the desired theatre acoustics, orchestra layout and overhang depth?

10.4 ACOUSTIC ADVANTAGES

A further advantage of installing orchestra lifts is acoustical in nature. Altering the height of the lift even by centimetres will result in a change of acoustics in the pit and in the auditorium. This concept will be dealt with in more detail in the following chapter.[2]

It is important that the various individual sections of the orchestra (i.e. strings, woodwind, brass and perussion) are not acoustically broken up by differing floor levels. If more than one lift is installed, the division between each should be calculated to suit the seating arrangements

1. CORRY, P. 40

2. Wagner achieved a similar effect when he designed the orchestra pit at Bayreuth. The six descending levels can be compared to six lifts of varying degrees (ch. 1, fig. 6).

specifically planned for an orchestra.[1] This is a further reason why more than three lifts can be a disadvantage in the pit design : the complexities of too many potential options makes for management problems.

10.5 ALTERNATIVES TO ELECTRICAL LIFT INSTALLATION

The erection of wooden demountable platforms offers an inexpensive alternative to the installation of electrical lifts. However, the advantages are fewer, and labour costs perpetual. Hand operated lifts may provide a suitable compromise if resources are limited, but these devices are realisitically suitable only for small orchestra pits.

11. THE ORCHESTRA PIT RAILING

The orchestra pit railing is normally positioned parallel to the auditorium tiers. Three important functions are realised by its existence :

A) A physical barrier is established between the orchestra and the audience to conceal the musicians. It is essential that the presence of the psychological gap is not further

1. The benefits of using risers or platforms are described in the following chapter. These features are an effective alternative to installing extra orchestra lifts. See ch. 3, para. 9.3 & 9.4

emphasised by unnecessary distraction from within the pit. The wall also helps to create an intimate environment for the musicians.

B) The pit railing has an important acoustical function. Depending upon its composition, certain acoustical attributes can be enhanced or diminished. For example, a sound-transparent cloth suspended on a metal frame will allow more sound into the auditorium, while a railing constructed of a hard, thick and smooth surface will direct the reflected sound toward the stage thereby improving the aural contact between the pit and the stage.[1]

C) For sunken orchestra pits, the railing is clearly an essential safety feature.

Of the four sections that constitute an orchestra, the brass and percussion produce the greatest volume of sound. By installing removable sections of the pit railing made from various surfaces (reflective, absorbtive or sound-transparent), any imbalance within the pit becomes adjustable almost regardless of the seating arrangement.

---

1. See appendix 1, para. 5 & 6

A railing removable in sections is a necessity should the conductor need to step out of the pit during rehearsals to make acoustic comparisons between the sub-stage and auditorium. The orchestra railing is also removed when the pit lifts are raised to house floor level.

12. THE PROPS GUARD

Accident prevention is a necessary aspect of pit design recognised by insurance companies world-wide. The props guard forms an extension to the perimeter of the overhang. Its function is to safeguard against the possibility of damage or injury to musicians or instruments should a prop fall into the pit. Although it is an essential feature of pit design, it is vital that the guard does not interfere with the acoustics of the theatre by functioning as an extended overhang. One possible solution is to suspend a strong, black sound-transparent material over a subtle framework fixed to the forestage edge.

13. ENTRY / EXIT DOORS

The choice of location for the orchestra pit doors is limited to the side walls. The design approach should anticipate the following points :

A) During performances, extended tacet sections encourage musicians to exit from the pit. The doors must be designed to allow minimal light into the auditorium so that the contact factor is not impaired.

B) Potential evacuation of the pit is a vital safety feature. Ease of exit, as well as instrument size must be taken into account when planning the door dimensions.

C) The orchestra pit doors also serve an acoustical purpose. Noise leakage from outside must be prevented by proper insulation. Insulation of doors is also a necessary feature for effective air-conditioning within the pit.

14. THE SAFETY CURTAIN

The standard position of the safety curtain is at the proscenium opening. Many German theatres have changed this position by bringing the fire curtain further towards the audience, encompassing the orchestra pit railing as well. The application of this feature is stipulated by varying safety regulations in each individual country, thus the option may not arise in the first place.[1] One disadvantage of this design is that it limits the potential adaptability

---

1. This design approach has been used locally at the Baxter Theatre in Cape Town.

of the orchestra pit : for example, the auditorium capacity cannot be expanded into the pit area.

15. STORAGE FACILITIES

Music stands, chairs and the larger instruments need to be stored in close proximity to the pit. Figure 9. shows a useful arrangement where a storage level has been constructed below the auditorium and orchestra pit floors. One of the advantages of this design is that labour is kept to a minimum. The bottom floor of a double-level lift and the area underneath the overhang may also provide convenient temporary storage facilities, although their concealed location does hinder accessibility.

16. RESEARCHING EXISTING STRUCTURES

Once the fundamentals of design have been absorbed, it is worthwhile to examine existing structures for ideas and inspiration. A period of research enables the designer to come in touch with a variety of orchestra pits and subjectively assess aspects of their relative success or failure. In this respect, a historical review of some of the post-inauguration alterations to the orchestra pit at the Nico Malan Opera House in Cape Town is apposite.

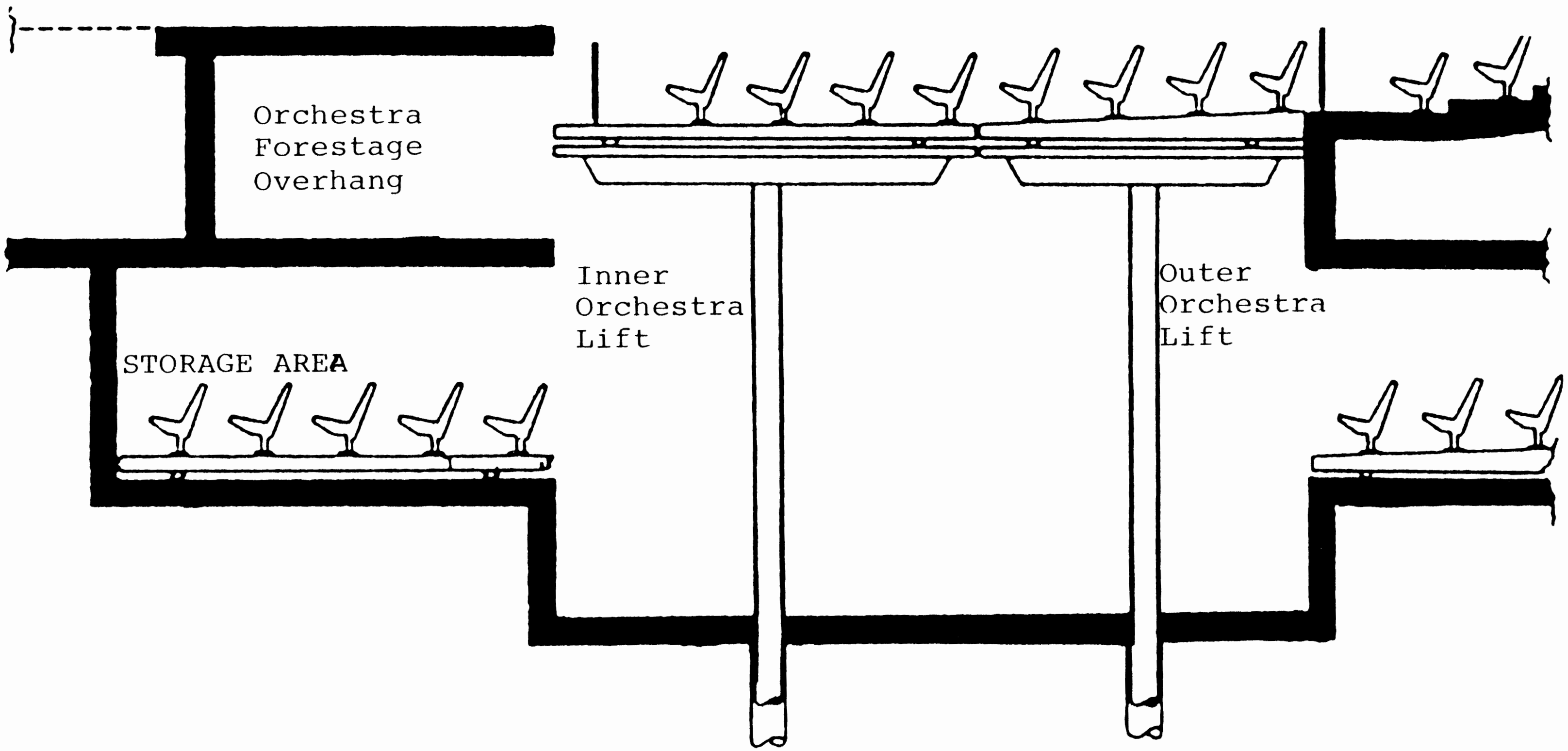


Fig. 9. Storage areas beneath the auditorium and orchestra pit floors

Adapted from Johnson, P. 18
(permission applied for)

17. THE NICO MALAN OPERA HOUSE

In 1971, the inauguration of the Nico Malan Theatre Centre did for South Africa what the Teatro San Cassiano did for opera : it was the first authentic opera house in the country. The design was influenced by world-wide research undertaken by the architects from as early as 1965. No specific opera house dictated the blueprint for the orchestra pit.[1] Instead, a detailed study of international opera establishments culminated in an original design, with an orchestra pit interweaving elements of many other designs.

The floor area of the original orchestra pit at the Nico Malan was 850 square feet (78.97 Sq. M.). It had been designed for a permanent orchestra of sixty musicians, a figure thought to be appropriate for the function of the theatre at the time.[2] Before the opening ceremony, the pit had already undergone its first alteration. In 1970, the principal conductor-to-be visited the pit during construction, and expressed his desire to improve contact by repositioning the intended pit front wall further from the forestage. This alteration was carried out.

---

1. Interview : Maciek Miszewski, architect, April 1991.

2. The average floor area was 1.32 metres squared per musician. Source document provided by M. Miszewski.

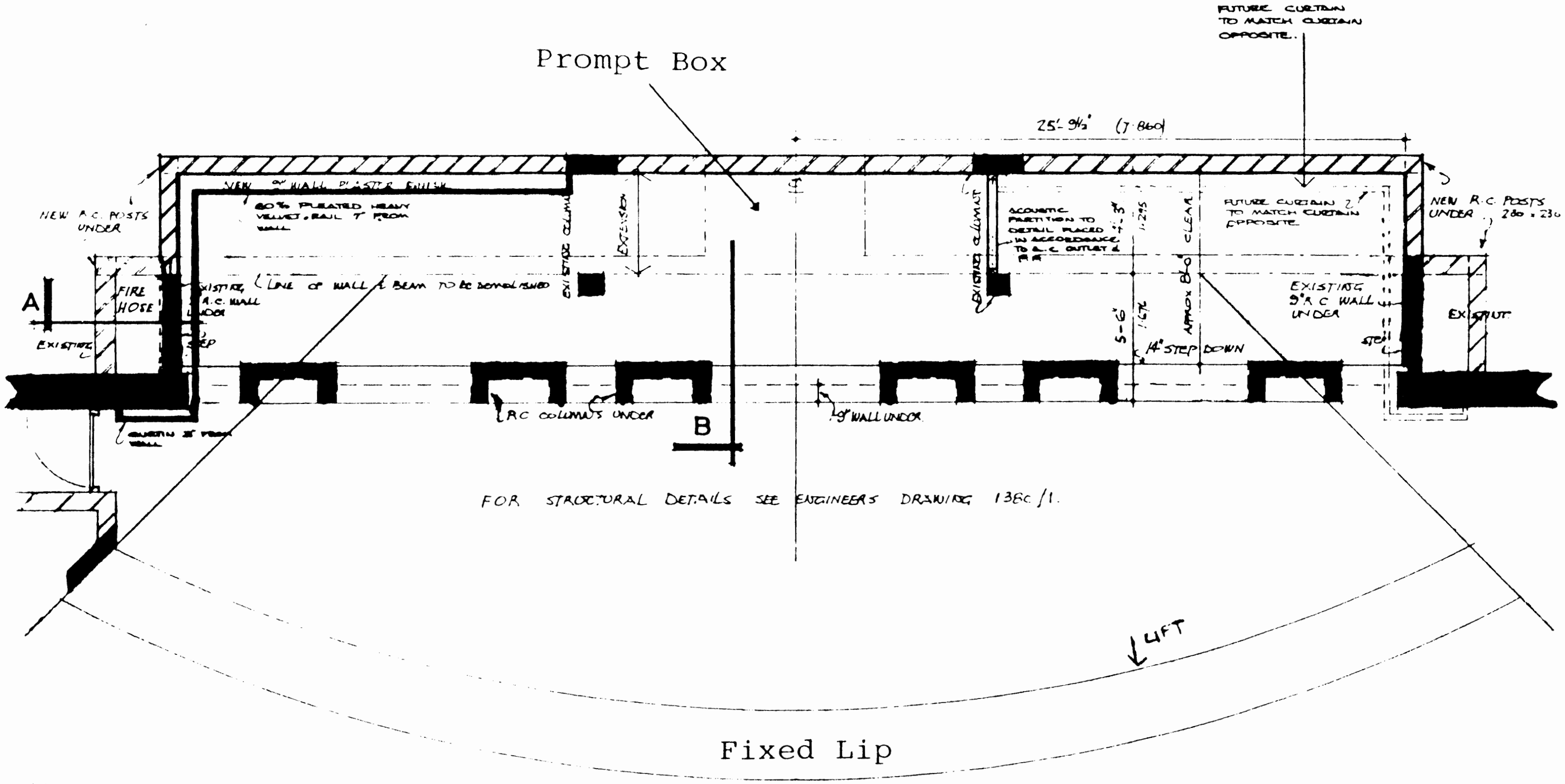
In June of 1975, plans were completed for a second enlargement to the orchestra pit (fig. 10). The revised design would accommodate up to seventy-two musicians. This increase in the resident orchestra size allowed programming of previously unfeasible large-scale productions.

18. EXAMINING THE POSSIBILITIES FOR ALTERATIONS

Before any alteration is brought to the point of construction, it is vital to try to anticipate and analyse the effect such changes are likely to have upon the orchestra pit environment. The possibilities for enlarging the pit area depend not only upon the structural limitations but more especially upon the contact factor.

At the Nico Malan Theatre Centre, the most appropriate solution resulted in the removal of the rear pit wall beneath the overhang. Originally a prompt box was situated between this wall and the front wall of the stage. A corridor on each side of the prompt box extended the full width of the stage, making this the easiest and most logical area to incorporate into the new enlarged pit (fig. 11).

The contact factor was least affected by increasing the depth of the overhang. However, two columns remain as



KENT MISZEWSKI HOCKLY AND PARTNERS Architects and Town Planners

NICO MALAN OPERA

ALTERATIONS TO ORCHESTRA PIT

Fig. 10. Plans for a new enlarged orchestra pit, 1975

(Reprinted with permission)

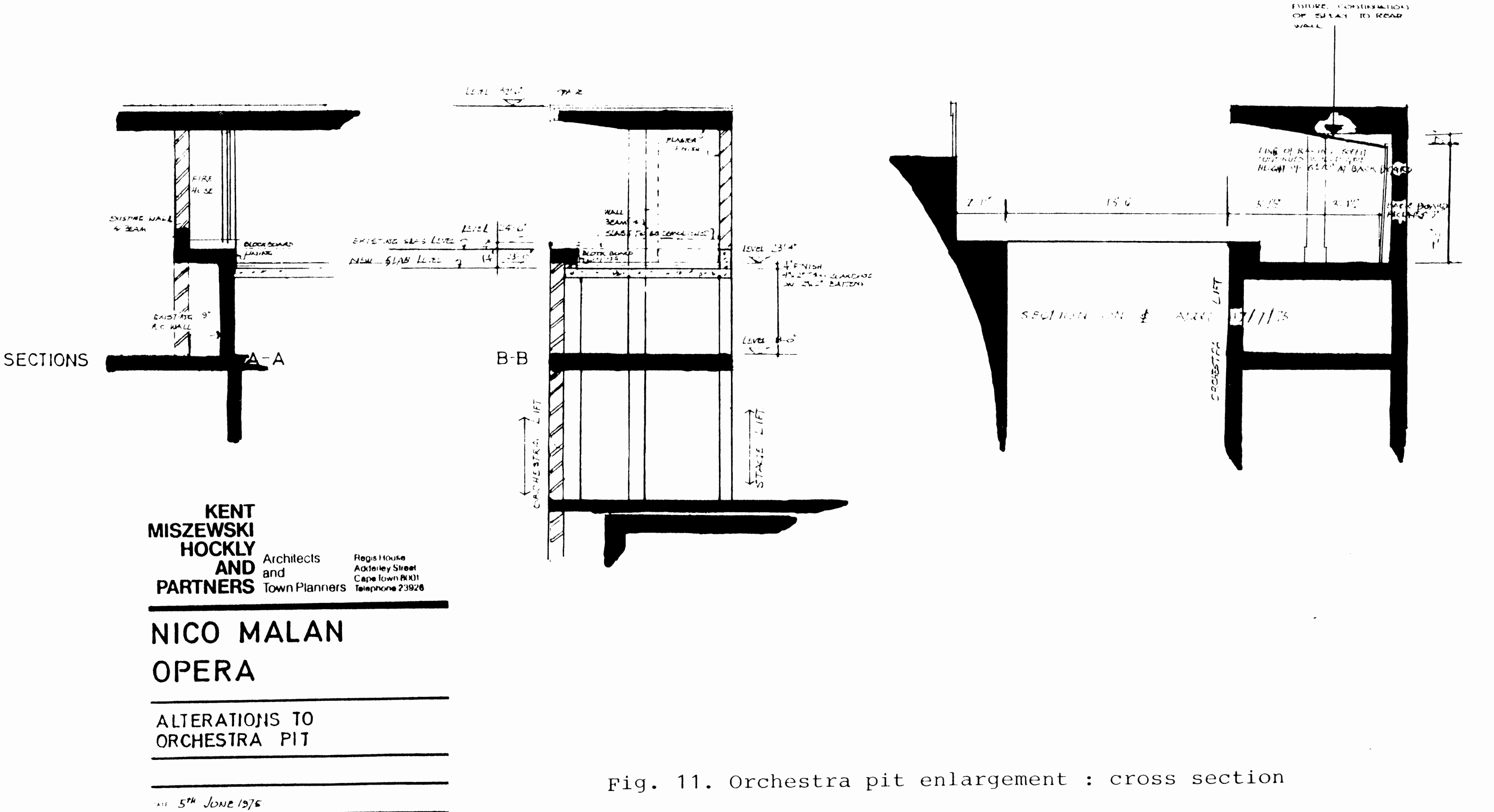


Fig. 11. Orchestra pit enlargement : cross section

(Reprinted with permission)

structural supports in place of the original wall. These not only create some obstruction, but limit the use of the surrounding area in terms of sectional seating. The acoustical impact of a deeper overhang is dealt with in the following chapter. Finally, because the opera department no longer uses a prompt, the loss of the prompt box is not significant.

DESIGN FEATURES AT THE NICO MALAN

19. THE ORCHESTRA LIFTS

The Nico Malan Opera House has three double-level orchestra lifts. Unlike the designs mentioned above (10.1), each of these lifts is positioned at right angles rather than parallel to the auditorium tiers. The two outer lifts travel between the pit floor and the forestage level. The centre lift performs an additional service in that it descends to basement level - opposite the central entrance to the orchestral rehearsal room. This rehearsal room has been constructed below the auditorium and is separated from the lift by a corridor which acts as an acoustic insulator between the two areas. The main function of the centre lift (used independently) is for the transportation of cumbersome instruments between the rehearsal room and the orchestra pit or stage.

20. THE PIT RAILING

No provision has been made to extend the capacity of the audience by making use of any of the orchestra gap area, but when the lifts are raised to house floor level the railing is removed for conferences. In 1988, the benefit of this design feature was also apparent when the original pit rails, removed in 1979, were replaced for acoustic reasons.[1]

21. ENTRY / EXIT DOORS

The installation of a double-leaf door ensures that minimal spillage of light occurs should one half be used during performances. Rapid exodus is facilitated by both leaves standing fully open.

22. DRAWBACKS IN THE DESIGN

Anticipating the consequences of every aspect of orchestra pit design is an ideal seldom achieved. Nevertheless, examining the drawbacks of a particular design does provide the basis for progressive improvement when considering future sub-stage environments. There are a few blemishes in

---

1. See ch. 3, para. 9.8

the Nico Malan orchestra pit which may facilitate this process.

22.1 FIXED LIP

A fixed lip is situated between the outer perimeter of the orchestra lift and the front wall of the orchestra pit.[1] This gap was not a feature of the original design, but was the consequence of the first alteration to the pit which took place during construction. When the lifts are raised to house floor level, the gap is covered by laying segmental timber floor units. This time-consuming process was the result of a dilemma : either to fulfil the aspirations of the principal conductor, or to ensure that the entire open area of the pit was occupied by the orchestra lifts (at that stage of construction the lift dimensions could not be modified). When the lifts are raised to forestage level the gap is not problematic because the orchestra pit railing functions as a safety feature and also conceals the gap effectively.

22.2 SOUND, LIGHT AND TEMPERATURE INSULATION

Placement of any light source in or about the pit is of

---

1. See fig. 10

primary importance if the orchestra gap is to remain effectively concealed. One problem with the doors to the Nico Malan pit is that a light was installed on the ceiling directly in front of the entrance. This causes some distraction to the audience and thus impairs the contact factor. Other than relocating the light, it should be possible to alleviate the problem by either dimming, screening or colour modification.

At the Nico Malan, noises from outside the pit doors are at times especially noticeable. This is not only distracting for the musician but also interferes with the acoustic function of the pit. This aspect is discussed in more detail in the next chapter, but it is important to establish that sound insulation is a vital constituent of the orchestra pit design.[1] By installing a double set of doors, greater all-round insulation would be ensured, both from within and outside the orchestra pit. However, door design must maintain effective access.

22.3 STORAGE FACILITIES

Apart from a compact percussion storage room situated on the basement level, no long-term storage facilities are

---

1. See ch. 3, para. 4.1

available at the Nico Malan for unwieldy instruments or orchestral furniture. Instruments such as the double basses, pianos, tuba and contra-bassoon are more or less permanently placed at the Theatre Centre and should be stored close to the orchestra pit.[1] Music stands, chairs and risers must regularly be transported to and from the pit. Lacking adequate dedicated storage facilities, basement corridors are used to compensate for this shortcoming.

23. SUMMARY

Despite some detail problems, the architectural design of the Nico Malan orchestra pit is very good, but only if the pit is used for the purpose for which it was designed - any deviation from the standard orchestra size results in cramped conditions. The orchestra gap is narrow enough to provide excellent eye-to-eye contact between conductor, orchestra and stage performer, yet the overhang does not inhibit the acoustics of this general-purpose theatre. Finally, the audience have an unobstructed view of the stage. Therefore the dimensions of the orchestra pit can be considered to have commendable proportions.

---

1. Preliminary opera rehearsals take place with the orchestra lifts raised to forestage level. The piano is transported from the basement via the centre lift onto the forestage. Consequently each time an opera is rehearsed in this way, the orchestral furniture needs to be cleared away from the lifts. This is a regular procedure because the ballet season runs concurrently.

Essentially a designer must endeavour to effect the correct perceptual relationships between the conductor, performer and audience. Fine contact equals fine perception. This is the first fundamental principle of successful orchestra pit design. Once this is acknowledged, the employment of each of the remaining features is based upon this principle, subject to the individual requirements of a particular opera house.

How do we judge the success of an orchestra pit? While features of the environment may influence the comfort or morale of the musician, there is little doubt that the sound emerging from the pit is the single most important criterion for successful orchestra pit design. The following chapter examines the acoustic design approach.

CHAPTER 3

Orchestra Pit Acoustics

ORCHESTRA PIT ACOUSTICS

> "I gave myself pains to master this bizarre science (of acoustics) but ... nowhere did I find a positive rule to guide me; on the contrary, nothing but contradictory statements ...I must explain that I have adopted no principle, that my plan is based on no theory, and that I leave success or failure to chance alone...like an acrobat who closes his eyes and clings to the ropes of an ascending balloon."[1]

1. THE BIRTH OF A SCIENCE

It was not until the end of the nineteenth century that acoustics was explored as a science.[2] Garnier clearly demonstrates that up until this time no scientifically proven guidelines had been established. In 1898, Wallace Clement Sabine made the first real breakthrough in this new field when he was commissioned to supervise the building of the Boston Symphony Hall. As a result of earlier experiments, Sabine had been able to define and measure the reverberation time.[3] He had "found that the reverberation

---

1. GARNIER Charles, L'Opera, Hachette (publishers), Paris, 1880. (written after the completion of the Paris Opera House, highly acclaimed for its successful acoustics).

2. Although little was known about acoustics as a science, earlier civilisations acknowledged proven methods. The recurring acoustic success of the amphitheatre is a clear indication that Garnier's success may have been more than "chance alone".

3. See para. 4.3 for definition.

time was proportional to the cubic volume of the room and inversely proportional to the total sound absorption." [1] The desired reverberation time of an auditorium could now be accurately calculated, and thus at least potentially realised in the design.[2]

1.1 BERANEK'S CONTRIBUTIONS

The following quote by Bradley, written in 1986, confirms the importance of Sabine's discovery:

> "Over the past 80 years the acoustical design of auditoria has been based almost entirely on an optimum reverberation time."[3]

However, in 1962, Leo Beranek suggested in his classic book, Music, Acoustics & Architecture, that the reverberation time was not in fact the most important criterion for the acoustic design of auditoria. After completing a research analysis of fifty-four halls world-wide, Beranek condensed the principal attributes of acoustical quality in a hall

---

1. PYLE Robert, "Terminology and History of Architectural Acoustics", The Horn Call, Vol. 19, No. 1, Oct. 1988, P. 39

2. SABINE Wallace C., Collected Papers on Acoustics, Harvard University Press, Cambridge, U.S.A., 1923, P. 25.

3. BRADLEY J. S., "Acoustical comparison of three theatres", Journal of the Acoustical Society of America, Vol. 79, No. 6, June 1986, P. 1827.

intended for the performance of music down to the following eighteen categories :[1]

1. Intimacy or presence
2. Liveness
3. Warmth
4. Loudness of the direct sound
5. Loudness of the reverberant sound
6. Definition or clarity
7. Brilliance
8. Diffusion
9. Balance
10. Blend
11. Ensemble (ease of hearing among performers)
12. Immediacy of response (attack)
13. Texture
14. Freedom from echo
15. Freedom from noise
16. Dynamic range
17. Tonal quality
18. Uniformity

1.2 IMPROVED COMMUNICATION

For the first time a universal music-acoustical language had been created. This was an important step toward better communication between musicians and theatre designers. Beranek aimed towards eradicating the ambiguity that had previously distorted the goals of both the designer and the musician. In so doing, it was now possible to communicate effectively how the environment affects the transmission of sound from the source to the listener. It is upon the same

---

1. "In the weighting of these attributes ... intimacy will be found to be nearly three times as important as any other one of the subjective musical-acoustic attributes that follow." BERANEK, P. 63 (see also the following reference)

foundation that this acoustical examination of the orchestra pit milieu is based. Although Beranek's overall results were not completely without fault, the above list of acoustical attributes provide a tenable basis for the purposes of this examination.[1] By defining each of these terms and relating them to the theatre as a whole, the opportunity to understand, describe and criticise the acoustics of the orchestra pit environment is presented. However, before each of the principal elements is considered, it is first appropriate to examine the relationship between the orchestra pit and the rest of the auditorium.

2. THE COUPLING FACTOR

The quality of sound enjoyed by modern theatre-goers is the result of the skillful use of various reflective and absorbtive surfaces which complement the sound source. The purely symphonic performer has the physical and acoustical advantage of being surrounded by such an environment. The concealed pit musician is less fortunate. Even partial exposure to such a rich sonic setting would significantly improve his contact not only with fellow instrumentalists, but also with the stage performers and the audience. This

---

1. Refer to : BARRON Michael, "The Subjective Effects of First Reflections in Concert Halls - the need for lateral reflections", Journal of Sound and Vibration, Vol. 15, No.4, 1971, P. 491 - 492, for further critical details.

relationship between the pit and the rest of the auditorium is termed the coupling factor. An increase in the orchestra gap depth improves this factor because the musician perceives a finer quality of contact.

The preceding chapter explains how in a closed orchestra pit, there is also a relation between the depth of the overhang and the depth of the orchestra gap. Thus, an improvement in the coupling factor may imply a shallow overhang which in itself influences the type of pit and auditorium acoustics. The musician's perception of contact is therefore limited by the desired theatre acoustic.

3. THE ORCHESTRA PIT - A NECESSARY EVIL?

The concealed position of the pit dictates many of its acoustic limitations even before its construction. Unlike the auditorium proper, where the acoustic is designed to shape the sound into its completed form, the primary function of the orchestra pit is to project sound out from this secluded spot. Instrumentalists are in the main isolated from the type of conditions that should enhance their full potential in sound. For these reasons, the pit musician perceives the by-product rather than the end product of his performance. Nevertheless, it is essential that the acoustician endeavours to provide optimum conditions within the pit in order to inspire musical excellence. His ability to achieve any measure of success in this respect is limited by the requirement not to interfere with the fundamental acoustic design of the theatre as a whole. While there are aspects that can be improved, it is important to bear in mind that for every acoustic action within the pit, there is an acoustic reaction in the auditorium. Any attempt to radically alter the intrinsic function of the orchestra pit as a sound projecting chamber will be counterproductive. This chapter attempts to examine, at least in part, the basis of this relationship.

PRINCIPAL ACOUSTICAL ATTRIBUTES.

4.1 NOISE EXCLUSION

The first prerequisite for any form of acoustic design is the exclusion of noise. The acoustic performance of a hall will seriously be affected if any unwanted sounds, such as traffic or airplane noise, pass through the auditorium. Similarly, every effort must be made to subdue noise levels within the theatre, for example, stage machinery and air-conditioning units. Even to the untrained ear, the effects of unwanted noise are unequivocal during the performance of quiet passages of music. Sound insulation is the main form of defence, but expert realisation of noise control measures for mechanical installation can minimise many of the problems that might otherwise have to be endured in the auditorium.

The threshold of audibility is less than approximately 10 dBA. For an auditorium, the permissible backround ambient noise is between 25 - 30 dBA and for a library approximately 40 dBA. Discomfort normally occurs when noise levels rise above 110 - 120 dBA.[1]

4.2 LOUDNESS OF THE DIRECT SOUND

The direct sound is the first sound to reach the listener's ears, i.e. it is the sound perceived before any reflections take place (fig. 1). In an orchestra pit, musicians perceive an abundance of direct sound due to the dense concentration of sound sources in such a small area. Unlike an auditorium, where the loudness of the direct sound decreases as the distance from the source increases, the decay of direct sound loudness is not an important consideration for the acoustic design of an orchestra pit because significant deterioration does not occur where the sound sources are

1. MILLER John & JEFF Charles, "Noise 1: The risks", The Architects' Journal, Vol. 187, No. 5, Feb. 3, 1988, P.49

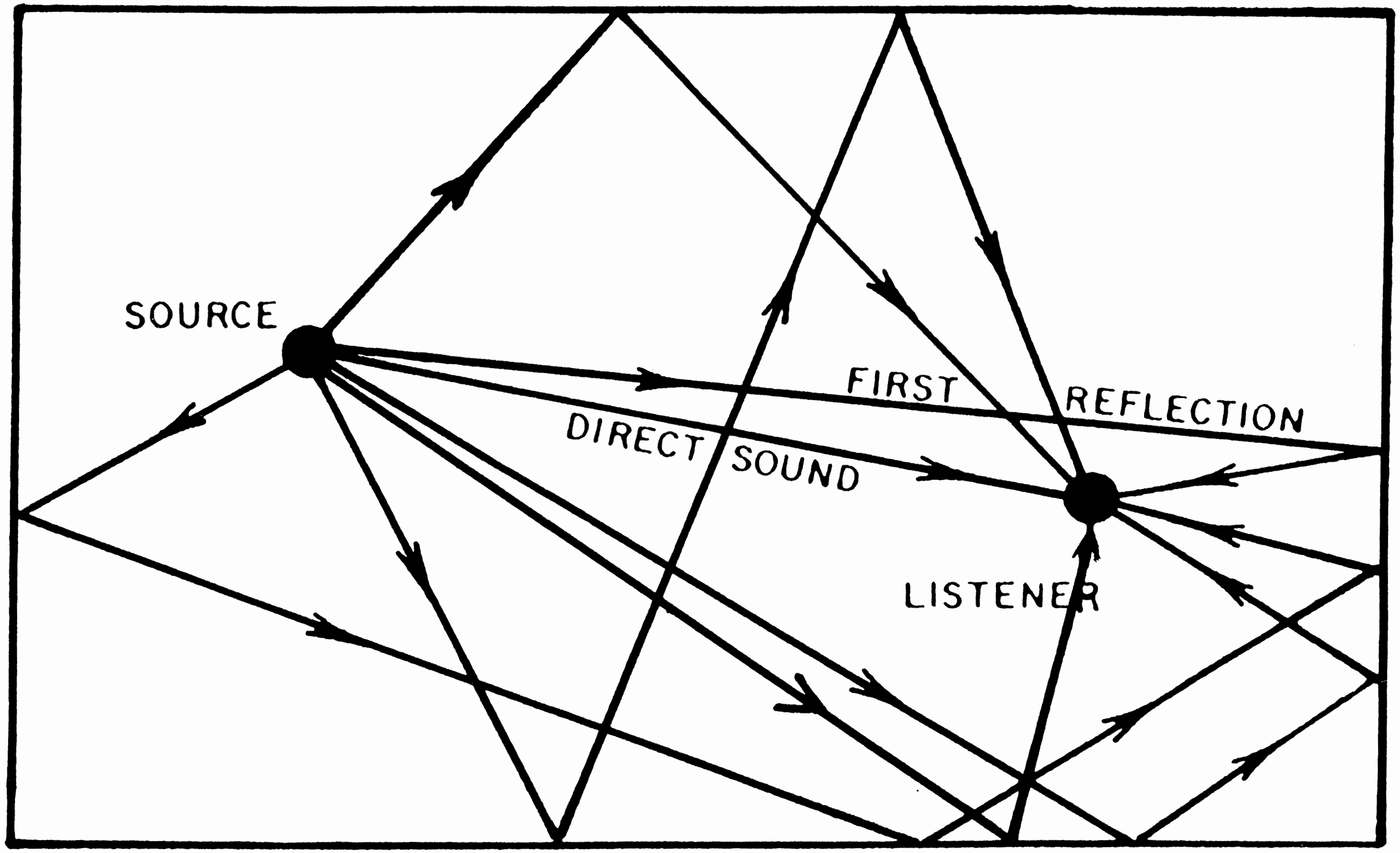


Fig. 1. Multiple reflections from the walls of a room of a single impulse produced by a sound source.

Adapted from Backus, P. 145
(permission applied for)

grouped within such a confined space.[1]

4.3 LOUDNESS OF THE REVERBERANT SOUND

Without reverberation, a room is said to be acoustically dead - it does not enhance the music in any way. Reverberation is the sound that remains reflecting once its source has stopped. Reverberation time is the duration it takes for this remaining sound to deteriorate to one-millionth of its original energy (or decay by 60 decibels).[2]

There is a direct relationship between the use of reflective surfaces and the reverberation time of a room. In an orchestra pit, the surfaces are thick, smooth and hard, to facilitate sound reflection. However, the orchestra pit is not a separate acoustic room because of the open area, or orchestra gap. This gap acts like a sound absorber since sound radiating from it returns only partially, and much later. The concentrated gathering of musicians in such a small area also has an absorbent effect. Therefore, the reflective character of the pit surfaces facilitate sound

---

1. If the path of a sound source is unobstructed, its "intensity is inversely proportional to the square of the distance from the source, so that doubling the distance reduces the intensity by a factor of four." BACKUS John, The Acoustical Foundations of Music, Murray, London, 1970, P. 143

2. PYLE 1988, P. 39

projection rather than reverberation.[1] The reverberation time in the pit is determined by the following factors : the cubic volume of the pit, the coupling factor, the reflective/absorbtive surfaces,the orchestra density and the pit dimensions (for example, the floor height and overhang depth).

"The optimum reverberation time for an auditorium is ... a compromise between clarity[2] on one hand and a satisfactory sound intensity on the other. For a given auditorium the best reverberation time will depend on the use for which it is designed as well as on its size (fig. 2)."[3] Consequently, the optimum reverberation time for the orchestra pit will be such that it complements the acoustics of the auditorium as an entirety.

If the orchestra lifts are lowered by thiry centimetres, the reverberation time within the pit is increased. An increase in the pit reverberation time leads to a decrease in the clarity perceived in the auditorium. This is one reason for keeping the reverberation time in the pit lower than in the

---

1. If the pit was to be more absorbent in nature, then much of the sound energy (intensity) would be lost. This would in turn hinder the distribution of sound throughout the auditorium.

2. See para. 4.9

3. BACKUS, P. 150

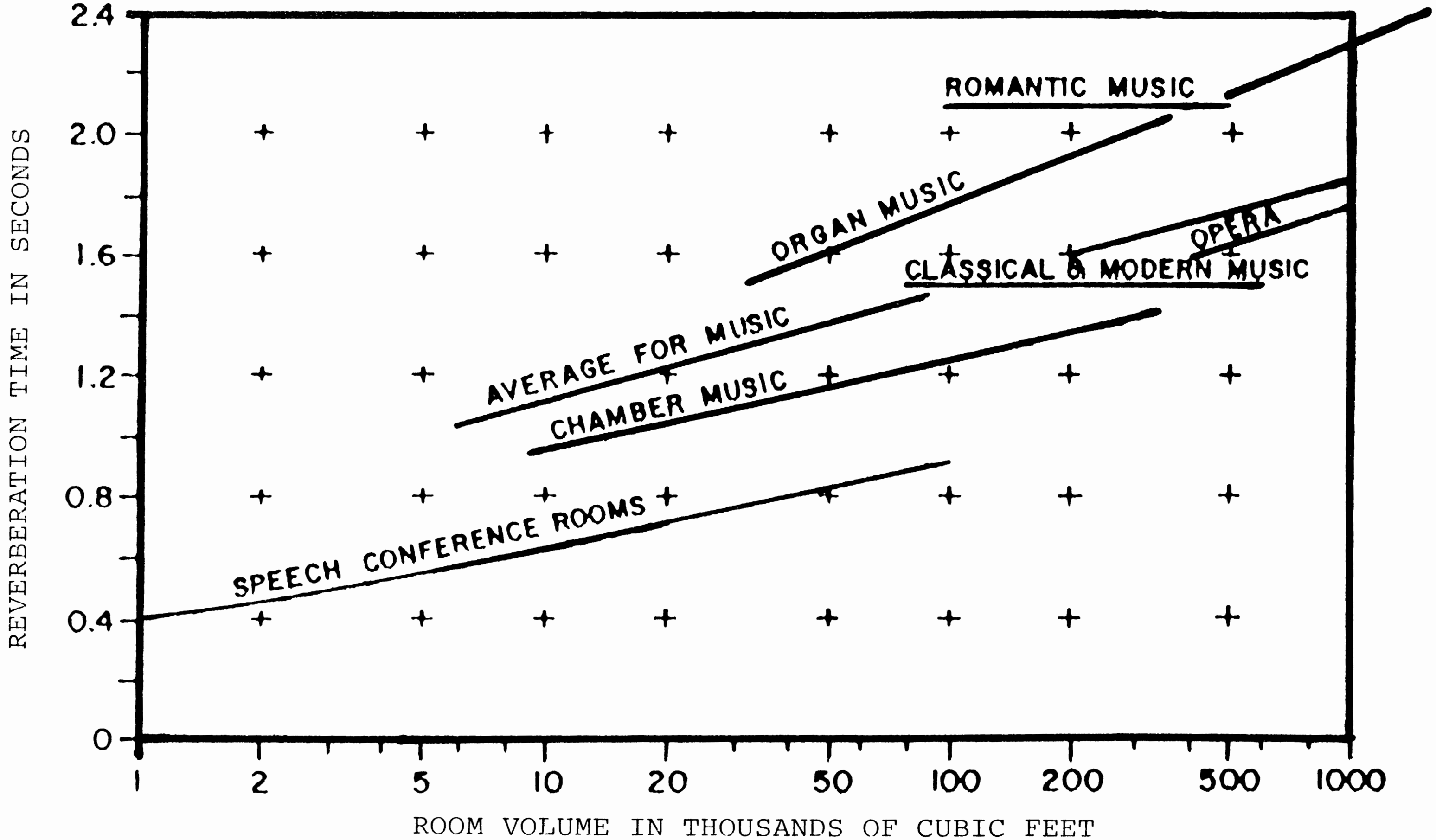


Fig. 2. Optimum reverberation time for auditoriums of various sizes and functions at a frequency of 500 cycles per second.

Adapted from Backus, P. 151

(permission applied for)

auditorium, yet not so low that the other principal acoustical attributes cannot be appreciated. By the same token, "uncontrolled reverberation is the arch-enemy of music - a truth to which organists under threat of torture might admit."[1]

Loudness of the reverberant sound is determined by the intensity of the reflections perceived and the duration of the reverberation time. There is a direct relationship between the intensity and the arrival time of early reflected sound : the earlier sound reflections have greater intensity. In the pit, because the nearby surfaces ensure early reflections, the intensity of the direct and early reflected sounds are perceived simultaneously. This in turn increases the loudness perceived : "the human nervous system seems to merge separate sounds arriving within about 50 milliseconds into a single stimulus".[2]

Depending upon the coupling factor, the low reverberation time combined with the intensity of the early sound govern, in one form or another, the characteristics of each of the pit's remaining acoustical attributes (this will become apparent as more of the objective acoustic design criteria

---

1. RAMSEY, P. 171

2. PYLE 1988, P.40

are delineated). Nevertheless, because it is possible to increase the reverberation time, and because musicians do not favour performing in a largely unenhanced environment, some form of compromise is inevitable.

4.4-5 LIVENESS AND WARMTH

"Dead" was the expression used to describe a room without reverberation. One of two terms is used to describe the opposite condition. A "live" pit refers to the presence of full-spectrum frequency reverberation, while a "warm" pit describes the presence of lower frequency reverberation. This distinction between full-spectrum and low frequency reverberation emphasises the importance of perception of warmth when appraising musical performance.

4.6 BRILLIANCE

The word "brilliance" is used when the music is rich in the upper harmonics. Such sounds are normally bright and clear, for example the piccolo or upper register of the violin. In an orchestra pit where the direct sound is predominant and musicians are densely grouped, the brilliance of the sound is normally far greater than that perceived in the auditorium. This is mainly the result of three factors :

A) The musicians are closer to the sound source.

B) Air absorbs and attenuates higher frequencies (above 4000 cycles per second) sooner than lower ones. This is a function of the distance travelled, i.e. for short distances the attenuation is small.

C) The pit front wall screens most of the upper harmonics, because high-frequency sound does not bend around corners. Screening does not occur when the listener has a direct view of the sound source, e.g. balcony seats.

4.7 DIFFUSION

Diffusion is the term used to describe the manner in which the sound has been distributed. If the listener feels that he is "surrounded" by (a combination of direct and reverberant) sound, then the diffusion can be described as being good. Irregular surfaces, such as those seen in the Boston Symphony Hall, facilitate random distribution of sound. " The key to the wonderful sound available ... in Carnegie Hall is the huge number of reflections set up by all the curves and whirligigs on each and every box, spread round the listeners in circle above circle. A hall with flat walls, and no projections to reflect some sound down, can never produce this richness of sound."[1] The combination of the flat, smooth surfaces, together with the low reverberation time make diffusion in the orchestra pit less than good. Whatever diffusion does occur is mainly the result of the non-parallel shape of the pit, the musicians and the orchestral furniture.

4.8 BLEND

Blend is also an important criterion for assessing richness of sound. Any substantial increase in the merging of sounds within the pit, for example by altering the floor height or increasing the overhang depth, will result in a decrease of clarity in the auditorium. Clearly, there is a relationship between blend and reverberation. The seating arrangement of the orchestra and the angle of the sound-reflecting surfaces (the overhang and open area ceiling tapers in particular) also influence the quality of blend within the pit.

4.9 CLARITY

Clarity refers to the clearness of the sound perceived and is a function of the energy of the early reflections. Due to

---

1. VAUGHAN Denis, "The full potential in orchestral sound", The Musical Times, Vol. 130, No. 1757, July 1989, P. 396

the low reverberation time, and the intensity of the early reflections in the pit, clarity is good.

4.10 BALANCE

The balance between the various sections of the orchestra and between the stage and the orchestra, basically depends upon two factors : the design of the pit and the conductor's control over the musicians. Closed orchestra pits have fewer balance problems because the relatively longer reverberation time facilitates the blending of orchestral sound. The overhang is also used to attenuate the louder sounding instruments placed under it, giving the conductor even more control.

4.11 ENSEMBLE

"The acoustical attributes of a performance environment that enable an orchestra (performers) to play with good ensemble are the ability of each musician (performer) to hear himself, the ability of a musician (performer) to hear all the others and the absence of time delay."[1] However, the accuracy required to play together demands more than just the above. The competence of the conductor and the performer

---

1. McCUE Edward, "Room Acoustics and the Orchestral Hornist", The Horn Call, Vol. 19, No. 1, Oct. 1988, P. 46

need to be considered. A musician can learn to "tune-in" to his fellow performer. In other words, it can also be a psychological rather than just aural form of contact.

4.12 TONAL QUALITY

Specific surfaces can absorb or emphasise particular frequencies which may in turn mar the tonal quality of a hall. Beranek used the term "tonal distortion" to describe this effect. Common examples of other types of tonal distortion include "ringing" (where a surface such as metal vibrates simultaneously at a particular frequency) and the flutter echo (where the sound from the source is bounced back and forth in quick succession, usually between two parallel walls, producing a type of flutter effect).

In orchestra pit design, particular attention must be given to avoiding the construction of any form of parallel surfaces that may cause a flutter echo. The confined dimensions of an opera pit are particularly susceptible to such characteristics. For this reason, not only the walls but even the underside of the overhang should be splayed or tapered to avoid parallelism.[1]

---

1. Some American pits have a straight front wall parallel to the back wall. These designs do not cause standing wave distortion because of the high internal absorption that takes place between these walls i.e. the concentration of musicians and the open area of the pit.

4.13 ECHO

The flutter echo should not be confused with echo itself: the two are entirely different. Similarly, because echo and reverberation are both the result of sound reflections, they are also frequently misunderstood. With reverberation, the sound reflections occur within a very short space of each other, while with echo, the reflection is so late that it is perceived as a separate sound. To qualify as an echo "the reflected sound path must be at least 55' (16.76 metres) longer than the direct sound path from source to listener, and the reflected sound must arrive at least .04 seconds after the direct sound".[1] It has already been noted that sounds arriving within approximately 50 milliseconds are perceived as a single stimulus (unless the intensity of the reflected sound is significantly greater than that of the direct sound - such instances only occur with focusing effects). Therefore it would be more accurate for the above figure to read 0.05 rather than 0.04 seconds.[2] Despite this, delayed reflections of this kind do not occur in the orchestra pit.

---

1. RIEDEL Scott R., "Acoustics in the Worship Space V", The Diapason, Vol. 79, No. 4, Apr. 1988, P. 16

2. See also BARRON, P. 483 (4.1.4)

4.14 ATTACK

If the musician is unable to hear his attack clearly, the way in which he begins a note, then definition (clarity) and ensemble will be among the acoustical qualities likely to suffer. However, the abundance of direct sound, the low reverberation time and the early side-wall reflections predominant in the acoustic design of orchestra pits facilitate the ease with which a musician can perceive his articulation. Consequently, pit musicians seldom voice complaints about attack.

4.15 DYNAMIC RANGE

> "Few buildings are designed in which noise levels as high as the threshold of discomfort will be generated. This occurs at around 120 dB(A). At the other extreme, it is unlikely that the architects' brief will call for backround noise levels as low as the threshold of audibility, that is, less than approximately 10 dB(A). All everyday sounds lie somewhere between these two extremes and, if not controlled, can give rise to the following undesirable effects : damage to hearing, loss or disturbance of sleep, interference with intelligibility of communication, lack of speech privacy and noise annoyance."[1]

Dynamic range refers to the scope of loudness in an auditorium. In an orchestra pit, the threshold of loudness is determined by the exclusion of noise factors, as it is

1. MILLER & CHARLES, P. 49

for the theatre in its entirety. However, unlike the rest of the auditorium, the range of loudness in the orchestra pit reaches uncomfortable levels, not only because of the intensity of the early reflections but more especially as a result of the orchestra seating arrangement. There is a direct relationship between the acoustic performance of a room and the distance between the sound sources (seating arrangement). For this reason, the sound sources are kept relatively close together.[1] It is not exceptional that the distance between, for example, the bell of a brass instrument and the person perceiving its direct sound be less than a metre.[2]

4.16 UNIFORMITY OF SOUND

Regardless of how efficiently a hall has been planned, there will always be certain acoustic weak spots. A typical example of poor uniformity in a hall can be caused when the balcony overhang is too large.[3] This type of configuration deprives the listener of the most important reflected sounds

---

1. See para. 10

2. When I worked as principal trumpet at the Nico Malan Theatre Centre, the back desks of the viola players placed cotton wool in their ears to protect them from the "unbearable" and uncomfortable loudness.

3. A local example is the Cape Town City Hall.

- those from the upper side walls i.e. lateral reflections.[1] The clarity of the direct sound path can also suffer as a result of this design. Depending upon the depth of the pit overhang, musicians seated beneath the forestage experience similar acoustic weak spots.

4.17 INITIAL-TIME-DELAY GAP

One important facet of acoustic design which remains unmentioned is the initial-time-delay gap. It is clear from fig 1. that direct sound takes the shortest possible route from its source to the listener, and is therefore the first sound perceived. Shortly after, the first reflected sound arrives. The term used to describe the time interval between the direct sound and the first reflection is called the initial-time-delay gap. Acousticians determine the "intimacy" of an environment by measuring this interval. An important feature of intimacy is the listener's sense of being close to the sound source : he may describe an intimate hall as having "presence". Although smaller areas tend naturally to be more intimate, it is possible to shorten the initial-time-delay gap in a larger area by erecting reflectors close to the sound source. The distance

---

1. MARSHALL Arthur, "Levels of Reflection Masking in Concert Halls", Journal of Sound and Vibration, Vol. 7, No. 1, 1968, P. 116

the sound will have to travel before it is reflected is then shortened, and in turn, the intimacy of the hall is improved. The longer the duration between the direct sound and the first reflected sound, the less intimate the hall will become. Acousticians agree that an initial-time-delay gap of twenty milliseconds and under is conducive to an intimate environment.[1]

It is interesting to examine the intimacy of an orchestra pit. Under normal circumstances, the close proximity of hard and smooth surfaces should help to create the type of conditions ideal for an intimate environment. Furthermore, because the early reflections are predominantly lateral, the resulting "body and fullness" of the sound should also theoretically contribute to an intimate environment.[2] However, because the balance is upset by the occasionally excessive intensity of the early sound, the intimacy of an orchestra pit can often be distorted (tonally).[3] Nevertheless, this does not imply that the auditorium as a whole suffers the same problem.

---

1. However, for an opera house the duration may be slightly longer. Beranek rated opera houses with an initial-time-delay gap of up to 24 milliseconds as excellent. P. 419

2. BARRON, P. 483 (4.1.5)

3. Relative to the coupling factor.

4.18 TEXTURE

This subjective acoustical attribute is based upon perception of the time intervals between each reflected sound, including that of the initial-time-delay gap. "Texture is not easily separated from the initial-time-delay gap".[1] In an orchestra pit this distinction is made more difficult by the fact that there are a greater number of early reflections compared with those perceived in the auditorium. Consequently, subjective impressions of texture are further distorted.

> "This list of eighteen terms concludes the description of the principal attributes of acoustical quality in a hall intended for the performance of music. Other attributes could undoubtedly be named, and some of the eighteen included here could be discussed in combination or split even more finely and the parts discussed separately. With the terms defined here a musician would be able to describe a concert hall that he likes as one in which orchestral music is live, brilliant, warm, intimate, clear, and adequately loud. He might say that the music played in the hall has good attack, the orchestra is balanced, and the performers hear each other well. And he might conclude that the hall is uniform acoustically, has no echo, and has a wide dynamic range."[2]

1. BERANEK, P. 449

2. BERANEK, P. 71

5. INDIVIDUAL ACOUSTICAL ATTRIBUTES

Historically, there has been much debate amongst acousticians regarding the importance of particular acoustical attributes. For example, following Sabine's discoveries, reverberation was regarded as being the primary feature of acoustic design. Beranek's investigations, published in the 1960's, led him to believe that the measurement he called intimacy was three times more important than any one of the other seventeen attributes listed. Then in 1978, Lothar Cremer claimed loudness was the most integral part of acoustic design. However, in the last decade, Cremer, Ando and Marshall expanded upon this by agreeing that in order of merit; loudness, diffusion, clarity and timbre[1] were the more essential acoustical attributes.[2]

Whatever individual parameters are deemed to be particularly vital for the acoustic success of a theatre, and however they are ranked in order of merit, it is important to bear in mind that the above views refer to the acoustics of the

---

1. Timbre is the characteristic quality of a sound produced by a particular musical instrument or singer. The acoustics of a hall directly affects timbre, e.g. tonal distortion, warmth, texture, et cetera.

2. VAUGHAN Denis, "Music and Building", The Musical Times, vol. 127, no. 1721, August 1986, P. 439

theatre in its entirety. The orchestra pit is not a separate division, but rather a separate constituent of this entirety. The criteria for its successful acoustic design should be such that they complement, rather than imitate the final sound perceived in the auditorium.

6. CONSIDERING ORCHESTRA PIT ACOUSTICS

Having related each of the acoustical attributes to the pit environment, and having discovered that a separate pit acoustic cannot exist independently of the theatre acoustic, one wonders whether there is any purpose in discussing "orchestra pit acoustics" as such. Are pit musicians the victims of circumstance? Beranek wrote : "if he (the musician) hears only the reflections from the nearby walls ... around him, he will fail to sense the acoustics ... (of the pit) at all."[1] Does this not apply to the musician's perception of orchestra pit acoustics?

It is clear that the reverberation time within the pit ought to be kept lower than that of the rest of the auditorium.[2] As a result, characteristics such as liveness, warmth, balance, blend and ensemble are impaired. The dense grouping

---

1. BERANEK, P. 69

2. See para. 4.3

of sound sources influences the occasionally excessive loudness of the early sound and thus the dynamic range. The abundance of early lateral reflections distort the intimacy and texture. The thick, smooth and hard surfaces account for poor diffusion. Consequently, each of these conditions do little to enhance the largely "raw" sound produced in the pit.

It is often ungratifying for the musician to acknowledge that what he perceives is but the nuclear essence of his participation. Only when his sound is exposed to the theatre as an entirety, does it achieve its full potential beauty, and this is generally out of his earshot. Thus, some form of compromise is necessary. By examining the historical background of the Nico Malan Opera House it will be shown how design features can substantially improve acoustic conditions within the pit. It is first appropriate however, to consider some of the remaining objective and subjective elements which influence the acoustician's choice of design criteria.

7. OBJECTIVE ACOUSTICS

Although established acoustic techniques, combined with scientific (i.e. replicable) proof, make it theoretically possible to design a theatre for a specific purpose, it is clear "that there is no single, ideal architectural solution to the acoustical design of a hall." [1] By the same token, there is no single, ideal acoustical solution to the architectural design of a hall. Modern theatre is expected to cope with the demands of a musical repertoire encompassing several centuries. The principal acoustical attributes required for the performance of Wagnerian opera, will differ radically from those associated with Mozartian opera. The latter requires a relatively short reverberation time to assist clarity and brilliance, while romantic opera will depend upon a longer reverberation time to facilitate warmth and blend (see fig. 2). Only when a consensus has been reached regarding the attributes most needed for the specific raison d'être of the theatre, can the acoustic consultant even begin to focus upon an appropriate design. Although the listener will have subjective opinions about particular aspects of musical performance, the musician, the critic and the composer generally agree upon the type of acoustical attributes that will best suit specific periods of music. For example, few would argue that impressionistic music demands a longer reverberation time than that preferred for the classical or baroque style.[2] Unfortunately

---

1. BERANEK, P. 481

2. Although Gregorian chant is thought to require the longest, in emulation of cavernous hardstone cathedrals and chapels.

for the acoustician however, modern theatre cannot confine itself to one particular period of music. In fact, certain theatres go beyond the limits of multi-purpose design, in that the hall is sometimes used for speech in addition to the performance of music.[1] However, as a general rule the two are incompatible. "With speech, clarity is of prime concern; with music, a blending of sounds without undue sacrifice of clarity is essential."[2]

Apart from considering the era of the repertoire performed, the acoustician also needs to distinguish between the types of music performed. For example, there is a significant difference between the acoustic function of an opera theatre and a ballet theatre. Opera musicians must constantly be aware of the conductor's control of balance and loudness when accompanying singers on stage. Such acoustic handling is not quite as vital for the ballet orchestra who dominate practically the whole aural perception.

8. SUBJECTIVE ACOUSTICS

Despite the complexities of choosing the correct objective

---

1. A local example is the Baxter Hall, Cape Town.

2. Keet Wilhelm, "Acoustical Design", Brochure : Nico Malan Theatre Centre, Cape Town, 1971.

criteria for acoustic design, the acoustician is also faced with the subjective element. Perception of sound differs greatly from person to person. This is not only influenced by the physical receptivity of an individual's ear, or the way in which sounds are directed at it[1], but more especially the skill required to listen.

> "You hear without wanting to, or without being able to suppress it, unless you put a plug in your ear. You cannot stop hearing. Listening is something else. You can either listen or not listen, and it depends upon what you are listening for. ... Listening, as an acquired skill, is absolutely essential for musicians. It is not essential for the average person. It is essential for anyone whose work has to do with communication."[2]

Consequently, not everyone is capable of assessing the acoustics of a theatre - it is an aptitude. However, of those who are qualified, appraisal remains purely subjective - "since when have orchestral musicians ever agreed about anything?"[3] The following quotations indicate the diverse range of criteria that exist. The conductor, Wilhelm Furtwaengler, expressed his opinion to Claudia Cassidy, music critic of the Chicago Tribune, thus : " The hall with

---

1. VAUGHAN, 1989, P. 395-7

2. KIEVMAN Louis, "Listening-Hearing", The Strad, Vol. 101, No.1207, P. 929

3. ROONEY Dennis, "Resounding Restoration", Vol. 98, No. 1171, Nov. 1987, P. 883

the best acoustics is the hall with the best performance." Dennis Rooney, of The Strad magazine, was keen to justify the fifty million dollars spent restoring Carnegie Hall in 1986 : " The acoustics of the rooms in which music is heard are often as important (if subliminal) a component of our response to a concert or recital as what was played and who played it."[1] An article in the Musical Times reiterates just how complex the variables of acoustic perception can be : "Every seat in the hall receives a different quality of sound, ... (one) can speak ... only about how sounds arrive at a particular seat."[2]

THE NICO MALAN OPERA PIT

9.1 PROSCENIUM REFLECTORS

As is standard practice with the inauguration of any theatre, the acoustical properties of the Nico Malan had to be reviewed once the opera house had been officially opened. Acousticians refer to this as the "tuning period". It is during this time that the opinions voiced by performers, distinguished members of the audience, critics, management

---

1. ROONEY, 1987, P. 879

2. VAUGHAN, 1989, P. 395

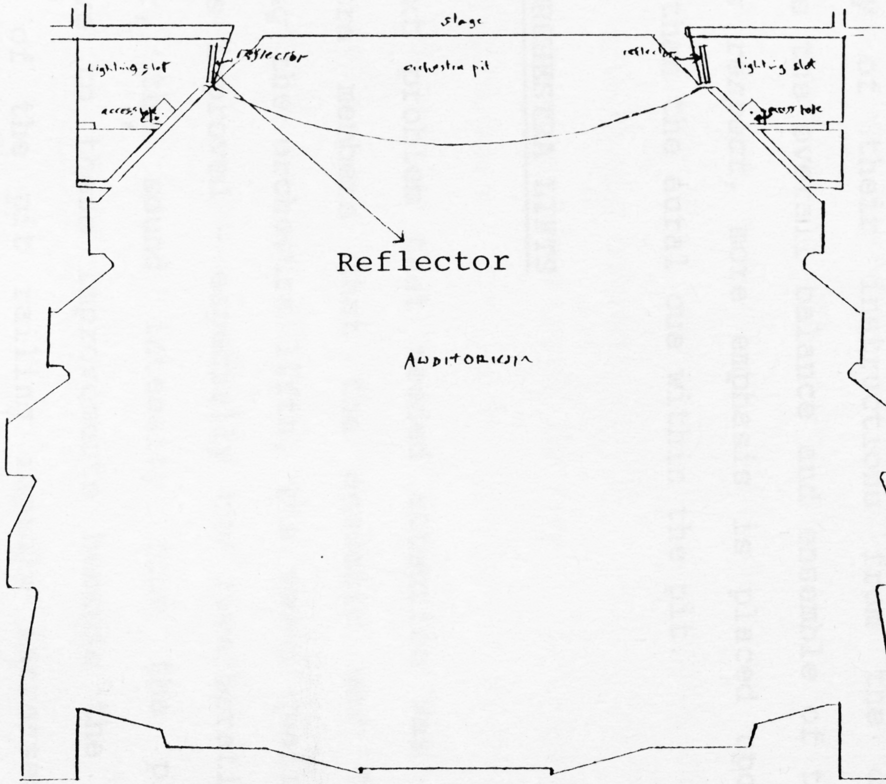
and theatre designers are assessed and implemented according to their viability.

Among the suggestions specifically related to the acoustics of the orchestra pit in 1972 was a proposal to improve the contact between the extreme sides of the orchestra. Other views indicated that the communication between the orchestra and the stage, and between the audience and the stage/orchestra, also needed improvement. The solution took the form of the drawings displayed overleaf (fig. 3).

By erecting adjustable concave proscenium reflectors on each of the upper side walls, all three problems had been significantly alleviated. It was the concave shape of the reflectors that was responsible for redirecting the sound evenly among all three areas. Installing the reflectors on the upper side walls ensured that the sound path was free from any absorbent obstructions, and in these ways, a relatively high degree of success was achieved.

9.2 LOUDSPEAKERS

Despite the erection of the proscenium reflectors, contact between the musicians under the overhang and the stage performers remained poor. This is a common problem in closed pit design because high-frequency sound does not bend around



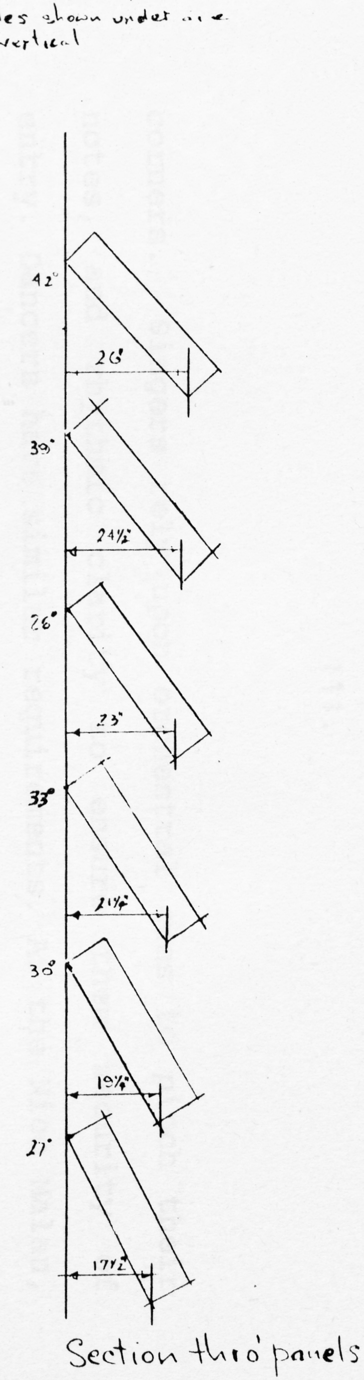


Fig. 3. Proscenium reflectors at the Nico Opera House (1972)

KENT, MISZEWSKI, HOCKLY & PARTNERS

ARCHITECTS AND TOWN PLANNERS

Rega House
112 Adderley St.
Cape Town.

Tel. 23926

(Reprinted with permission)

corners. Singers rely upon orchestral cues to pitch their notes, and rhythmic clarity to ensure them security of entry. Dancers have similar requirements. At the Nico Malan, one practical, albeit artificial method of improving the quality of contact involved placing loudspeakers at various positions on both sides of the stage, fed by microphones from the pit. While this does not improve the contact for the musicians, it is relatively successful for the performers on stage. The musicians, however, receive the majority of their instructions from the conductor who controls the overall balance and ensemble of the orchestra. *In this respect*, more emphasis is placed upon the visual rather than the aural cue within the pit.

9.3 ORCHESTRA LIFTS

The next problem that needed attention was complaints by orchestra members that the acoustic was "too dry". By lowering the orchestra lifts, the sound quality within the pit was improved - especially the reverberation and blend. However, the sound intensity from the pit diminishes relative to these improvements because the the screening effect of the pit railing rapidly increases with depth. Consequently, both the clarity and the intensity of the string sound in particular, were adversely affected. The only feasible way to combine the benefits of these diametrically opposed attributes (blend & clarity), was to let the lift remain at a lower level while the strings were raised on platforms.[1] In this way it was possible to maintain a suitable balance between the two.

9.4 RISERS

Although this was an effective way of improving the sound quality within the pit, other problems arose as a result. The balance and ensemble of an orchestra are upset if the musician experiences difficulty hearing himself or the other sections of the orchestra. Musicians on raised platforms tend to hinder this contact because most of their sound travels upward and outward.[2]

This concept was realised by even the earliest of Greek theatre designers - the sound source being at the bottom of a hill. Much of the intensity and quality of sound is lost if the seats are not raked upwards. Therefore, the use of risers within the pit has the exact opposite effect, and the acoustics for those musicians on floor level are inferior.[3]

---

1. The height of these platforms range from 17 - 30 centimetres. Each riser is placed beneath individual chairs.

2. Particularly the strings whose f-holes aim upwards.

3. The orchestra pit at the Bavarian National Theatre in Munich is designed in exactly the opposite way to the pit at the Festspielhaus in Bayreuth : each level is ascending rather than descending. In this way the above effect is avoided.

9.5 STAGGERING THE FLOOR HEIGHTS

While this arrangement is disagreeable for those not seated upon a platform, it is a distinct advantage for the sound quality perceived by the audience. Another way of achieving a similar result is by lowering certain sections of the orchestra lifts. This method is also an effective means of controlling the balance amongst the various sections. Wagner made use of this concept when he designed the orchestra pit at the Festspielhaus in Bayreuth. By arranging the different sections of the orchestra on six separate descending levels (see ch.1, fig.3), he obtained excellent balance throughout the auditorium. The benefits were not so pleasant for the brass players isolated on the bottom level - the effect being quite the opposite. " The brassy clamour was amplified a hundred times by the walls of the pit, and it seemed inconceivable that this horrible racket should emerge in the auditorium as pure tonal beauty."[1]

9.6 OVERHANG

The architectural advantages of the overhang have already

1. WECHSBERG Joseph, The New Yorker, Aug. 18, 1956. (Written after a listening experience in the Festspielhaus opera pit.)

been outlined, but we need to examine the acoustical benefits. The depth of the overhang contributes greatly to the acoustic of the theatre. At the Nico Malan, the relationship between the area of the overhang and the area of the pit in total is approximately 1 : 3. By way of comparison, the correlation for the Festspielhaus in Bayreuth is 3 : 4. In the latter example, the result is an exaggerated blending of sounds giving poor clarity - an ideal acoustic for the repertoire performed, namely Wagnerian opera. However, such attributes are by no means beneficial to the performance of Mozartian opera which, we believe, thrives upon clarity. Clearly, a completely open pit would be ideal for this purpose. Nevertheless, most theatres, including the Nico Malan, are expected to cater for a diverse range of productions, and therefore need to find a suitable balance between the type of acoustic complementary to baroque, classical, romantic and modern opera. For this reason, the 1 : 3 ratio provides adequate conditions with compensation by sensitive musicians, for such a broad range of performances.

9.7 ORCHESTRA PIT RAILING

In 1979, Akoestiplan, acoustical consultants to the "Nico Malan" opera complex, submitted a report recommending further alterations likely to improve the orchestra's sound quality. One of the proposals included removing the orchestra pit railing. Listening tests were carried out with and without the pit railing. The latter test revealed that the "orchestra sounded fuller and the sound had more presence. This was especially noticeable for the strings."[1] Subsequently the railing was removed and replaced with sound-transparent curtains mounted on wrought iron railings. This improved not only the sound quality but also the sound intensity.

9.8 CHANGING THE AUDITORIUM SURFACES

In 1988, several major alterations were completed at the Nico Malan. Renovations to the auditorium included the removal of all carpeting and alterations to the seating design. The net result was that the absorbency was significantly reduced. The reverberation times had increased in the mid-frequencies by approximately thirty per cent. Opera singers had for years complained about having to "force" their voices in order to project their sound into the auditorium. The situation had now turned about. It is interesting to examine how these alterations transformed the acoustic of the opera house and what influence they had upon the pit.

---

1. See appendix I, para 6 (i)

As a result of the increase in reverberation times in the mid-frequencies, the Nico Malan Opera House was now more live. Several complaints had been filed regarding the "overpowering" orchestral sound which interfered with the balance between the stage and the pit. Therefore, instead of endeavouring to project the sound out of the pit, as was the case before, measures now had to be taken to reduce the intensity. In 1988, Akoestiplan's recommendations to alleviate the problem included replacing the pit railing with sound reflecting panels. In turn this would also help increase the orchestral blend and the contact between the pit and the stage. In order to dampen the louder instruments, the brass and percussion sections, it was recommended that sound absorbing curtains be used. The orchestral balance and ensemble could then also be further improved by introducing screens between the louder and the softer sounding instruments (e.g. the timpani and the double bass sections).

In February 1992, the proscenium reflectors were removed because they were considered to be no longer of use following the alterations to the opera house. The orchestra members, unaware of the removal, did not notice any difference.

10. ORCHESTRA SEATING PLAN

The above historical review of the Nico Malan Theatre Centre demonstrates the acoustic significance of various different design features. Although each of these features can facilitate superior conditions for the pit musician, there is one very important aspect of acoustic design which has received little attention thus far : orchestral seating. "When I listened to Muti rehearse the Philidelphia Orchestra, I stopped him. "Ricardo," I said, " pull the orchestra together more and move them back five feet." He came out into the hall to listen with me. When the orchestra began to play again, the room fairly shook with sound. "Voila!" I said to him."[1] The way in which the various sections of the orchestra are assembled, and the amount of floor space required for each musician can alter the acoustic of the pit/auditorium dramatically. Each orchestra must embark upon a search to find the most suitable seating arrangement complementary to the inherent acoustic of the theatre. For the musician, the reward of such endeavours is an atmosphere further conducive to the emotional expression of music: " An acoustical environment that regularly inspires excellence from the musicians undoubtedly leads to

---

1. ROONEY Dennis, "Issac Stern speaks about the `new' Carnegie Hall", The Strad, Vol. 98, No. 1171, Nov. 1987, P. 884

memorable listening experiences for the audience."[1]

11. THE FUTURE OF ORCHESTRA PIT ACOUSTICS

Modern computer technology makes it possible to simulate acoustic environments. In this way, much of the costly "experimentation" that takes place during the tuning period is avoided. In 1995, when the Budapest Opera House is due for completion, it will be of interest to the entire opera community whether or not Nicholas Edwards, consultant to the Symphony Hall in Birmingham, can fulfill his promise to set new standards for opera acoustics.

> "... the Hungarian State Opera have told us they want a new opera house with acoustics like Birmingham's Symphony Hall. I think this will put them in the vanguard of a new movement in opera house acoustics."
>
> "My approach is to make it possible for the opera conductor to choose the acoustic to suit each performance. It should be possible for a conductor to achieve a warm, reverberant sound as in Symphony Hall, but equally it should be possible to achieve an intimate, dry acoustic. This can be done in an opera house which has a basic `signature' sound and adjustable acoustic devices similar to those in Symphony Hall."[2]

Here lies the hope for future orchestra pit designs.

---

1. McCUE, 44

2. EDWARDS Nicholas, "The New Generation in Acoustics", The Musical Times, Vol. 132, No. 1789, Mar. 1992, P. 117

CHAPTER 4

Comfort in the Orchestra Pit

COMFORT IN THE ORCHESTRA PIT

> "We require from buildings, as from men, two kinds of goodness; first, the doing of their practical duty well ; then that they be graceful and pleasing doing it."[1]

The designer must endeavour to create an environment that inspires musical excellence. This is especially true of the dark, concealed nature of the orchestra pit, where instrumentalists dressed in murky attire repeat seemingly countless performances in what is little more than a sound projecting chamber. Under such circumstances, it is hardly surprising that the pit musician becomes especially aware of the shortcomings of his working environment. Other undesirable conditions, such as a muggy atmosphere, uncomfortable seating and inadequate lighting are unnecessary, avoidable factors likely to impinge upon morale, hindering performance potential. Air-conditioning, chair design and lighting are three significant aspects which influence the pit musician's judgement of a comfortable sub-stage environment.

---

1. RUSKIN John, The Stones of Venice, 4th ed.,George Allen Publishers, Kent, U.K., 1851

1. AIR-CONDITIONING

The term air-conditioning was first used in 1911. Although there had been several earlier attempts to condition the air, it was only during the following decade that the first plants were installed in theatres.[1]

The precise function of an air-conditioning unit is to control simultaneously the various factors that influence the atmospheric environment. It is specifically designed "either for the comfort of human beings or animals or for the proper performance of some industrial or scientific process."[2]

1.1 THE COMFORT FACTORS

Essentially there are four comfort factors : temperature, humidity, motion and purity. If the balance between these elements is upset by even a minor fluctuation, it will significantly affect the musician's perception of comfort. For example, a human being's body blood temperature should remain as close to 37°C as possible. Although this

---

1. KING Guy, Basic Air Conditioning, Nickerson & Collins Co., Chicago, 1965, P. 6

2. JONES William P., Air Conditioning Engineering, 2nd ed., Whitstable Litho Ltd., Kent, U.K., 1975, P. 1

temperature varies slightly from person to person, a change of even a few tenths of a degree is sufficient to create discomfort. If the temperature were to change by several degrees death would result. It has been found that "under typical average conditions a person feels comfortable when the hands and feet are 89 F (31.66°C), and the body and head are from 92 F to 94 F (33.33°C to 34.44°C)."[1] This is best achieved with an ambient temperature of approximately 21° C.

However, each comfort factor is related to others. Even if the temperature were to remain within the above range the musician may still feel discomfort. For example, the recommended level of relative humidity [2] is somewhere between 40% - 60%.[3] Above this, regardless of temperature, the air will feel muggy, below, the nasal passages will start to become very dry.

Velocity of air motion can also effect the musician's perception of comfort. The affect of air movement is clearly demonstrated with the use of an electric fan : the skin

1. KING, P. 27

2. Relative humidity is the ratio between the amount of water-vapour in the air and the maximum amount of water-vapour air can hold.

3. CROOME Derek J., & ROBERTS Brian M., Air Conditioning and Ventilation of Buildings, 2nd Edition, Pergamon Press, Oxford, U.K., 1981, Vol.1, P. 124

temperature is reduced. Thus, a balanced air velocity should result in neither draughty nor stuffy conditions.[1]

The final precondition for a comfortable pit environment is air purity. Bacteria, toxic gases, dust and odours should all be removed as effectively as possible.[2] However, absolute air purity, as found for example in hospital surgical rooms, is an economic impossibility for the orchestra pit environment.

2. OPERA HOUSE AIR-CONDITIONING

Two criteria contribute to the complexity of balancing the comfort factors outlined above. First, perception of comfort varies - no one condition will satisfy everbody. Second, different environments demand different conditions. For example, the air-conditioning requirements for a cinema and a discothèque are opposed.

The opera house represents an even greater challenge for the designer - three separate environments are in use at once : the stage, the auditorium and the orchestra pit. The audience are passive, the stage performers mostly active,

---

1. CROOME & ROBERTS, P. 122

2. BUTTERY Helen, "Fantasy or Fact?" (sick building syndrome), Interior Design, Nov. 1987, P. 38-9

and the pit musicians engage in relatively light but varying muscular activity. Thus, combining these three air conditions under one roof requires a similar approach to that adopted for the acoustic and architectural design of a theatre. Indeed, all three approaches are directly related. For example, the correct architectural design of the pit will avoid congestion which in turn facilitates the air-conditioning process. The correct acoustic design must ensure proper sound insulation if the orchestra pit is to function effectively as a sound projecting chamber. In this way the pit is also insulated against heat loss and draughty conditions.[1] Finally, extraneous noise at levels likely to interefere with the acoustics of the pit and theatre can be avoided with expert installation of noise-generating components.[2]

Thus far, we are assuming that an orchestra pit requires a separate air-conditioning unit but this is not always the case. The decision to install a separate plant will depend mainly upon the coupling factor. An examination of the air-conditioning history at the Nico Malan Opera House

---

1. In 1740 it was established that temperature affects the speed of sound. However, in terms of theatre acoustics, the effects are insignificant. (Hunt Frederick V., Origins in Acoustics, Yale University Press, New Haven, 1978, p. 109-111).

2. See ch. 3, para. 4.1

demonstrates this point and further highlights the relationship between air-conditioning, acoustics and architecture.

3. AIR-CONDITIONING AND ACOUSTICS

Originally, only one air-conditioning unit was installed at the Nico Malan opera auditorium. This plant catered for the needs of the entire auditorium.[1] It was not until 1975, after the enlargement to the orchestra pit, that air-conditioning problems became apparent. As a result of the increased depth of the overhang (coupling factor) and orchestra size (density), musicians began to complain about the effective temperature.[2] An extractor fan was installed behind the back wall of the pit. In this way, an air flow between the ceiling punkah louvres (supply air vents) in the auditorium, and the extract fan in the pit was created. This was minimally successful. In order to augment the air motion, the velocity of air supplied through the front ceiling punkah louvres, those directly above the orchestra pit, was increased.

---

1. The stage is not air-conditioned.

2. Effective temperature is the temperature perceived by the musician. For example, if the supply air is at 18 degrees Celsius, inadequate air motion may result in the musician perceiving the pit temperature to be 22 degrees Celsius.

demonstrates this point and further highlights the relationship between air-conditioning, acoustics and architecture.

3. AIR-CONDITIONING AND ACOUSTICS

Originally, only one air-conditioning unit was installed at the Nico Malan opera auditorium. This plant catered for the needs of the entire auditorium.[1] It was not until 1975, after the enlargement to the orchestra pit, that air-conditioning problems became apparent. As a result of the increased depth of the overhang (coupling factor) and orchestra size (density), musicians began to complain about the effective temperature.[2] An extractor fan was installed behind the back wall of the pit. In this way, an air flow between the ceiling punkah louvres (supply air vents) in the auditorium, and the extract fan in the pit was created. This was minimally successful. In order to augment the air motion, the velocity of air supplied through the front ceiling punkah louvres, those directly above the orchestra pit, was increased.

---

1. The stage is not air-conditioned.

2. Effective temperature is the temperature perceived by the musician. For example, if the supply air is at 18 degrees Celsius, inadequate air motion may result in the musician perceiving the pit temperature to be 22 degrees Celsius.

Although the air-conditioning problem in the orchestra pit was alleviated, the solution was not without drawbacks which eventually pointed to the need to install a separate unit. The consulting acoustician, Wilhelm Keet wrote :

> "The matter regarding the air-conditioning noise level in the Nico Malan Opera House was recently discussed with Mr Pieter de Villiers (Consulting Mechanical Engineer). He was surprised to learn about the high velocity of air currently being supplied to the auditorium. According to him it is much too high. That also explains why the noise levels are so high - much higher than ever before. ... approximately 15 dB higher than it was during commissioning! No wonder there are complaints about bad acoustics and poor balance. I personally regard that as the largest part of the problem."[1]

Five years later the situation had not improved :

> "I should point out that Mr. P. de Villiers of C A du Toit & Partners is of the opinion that the air volume is too high and should be reduced...
>
> Both Mr. Van Pareen (Chief Technician, Air-conditioning) and myself are very reluctant to put this into practice as the orchestra pit relies entirely on the auditorium for its conditioned air. ... reducing the air volume to the auditorium could, in fact, make conditions in the pit completely unbearable. Further,.. reducing the air quantity will <u>definitely</u> have an effect on the temperature control."[2]

---

1. Letter from Akoestiplan to the Technical Director of the Nico Malan (19.09.1980). See appendix II for full original text.

2. Letter from the Technical Director of the Nico Malan to the Cape Provincial Administration (02.05.1985). See appendix II for full original text.

In 1987, a decision to solve both the acoustical and the air-conditioning problems was made :

> "It should be possible to reduce the velocity of the air entering the auditorium once the orchestra pit air-conditioning unit has been installed. The noise from the vents in the front of the auditorium is particularly noticeable, even to the unaided ear."[1]

4. AIR-CONDITIONING AND ARCHITECTURE.

Once it had been decided to install a separate system, the architectural limitations needed consideration. Mr. De Villiers (Consulting Mechanical Engineer) pointed out that an ideal design would distribute the supply air through the orchestra pit floor.[2] This method provides excellent distribution of either hot or cold air.[3] However two factors influenced the decision not to adopt this design type :

A) Finance : at the time, underfloor air-conditioning was a new concept, thus installation under any circumstances would have been expensive.

---

1. Letter from the Technical Director of the Nico Malan to the Cape Provincial Administration (02.06.1988). See appendix II for full original text.

2. Interview : Pieter de Villiers, June 1991.

3. The State Opera House in Pretoria and the Sand du Plessis Theatre in Bloemfontein use this method of air-conditioning.

B) More importantly, the orchestra pit lift would have caused a major structural restriction making it entirely impractical to install a unit of this type.

In the event, the side walls of the pit presented the only practical alternative. The front wall was fitted with supply air diffusors linked to a main galvanised duct. At the rear of the pit a greater number of extract grids were strategically positioned behind a false wall. This arrangement ensures the air is evenly distributed throughout the pit (fig. 1). If the supply air temperature is diffused at 16°C, the effective temperature in the pit is between 18.5°C and 21°C depending upon the air velocity. This is a suitable comfort level.[1] The air-conditioning problem in the pit was thus alleviated. The front auditorium punkah louvres were then rebalanced to their original settings, thereby reducing the high noise levels.

5. THE SCANNER BOARD.

Despite the success of this air-conditioning plant, one important factor was not considered. Unlike the main auditorium unit, no separate scanner board had been

1. Interviews (June 1992) : both Mr. Van Pareen and Mr. De Villiers agree that this is a suitable temperature for the orchestra pit environment.

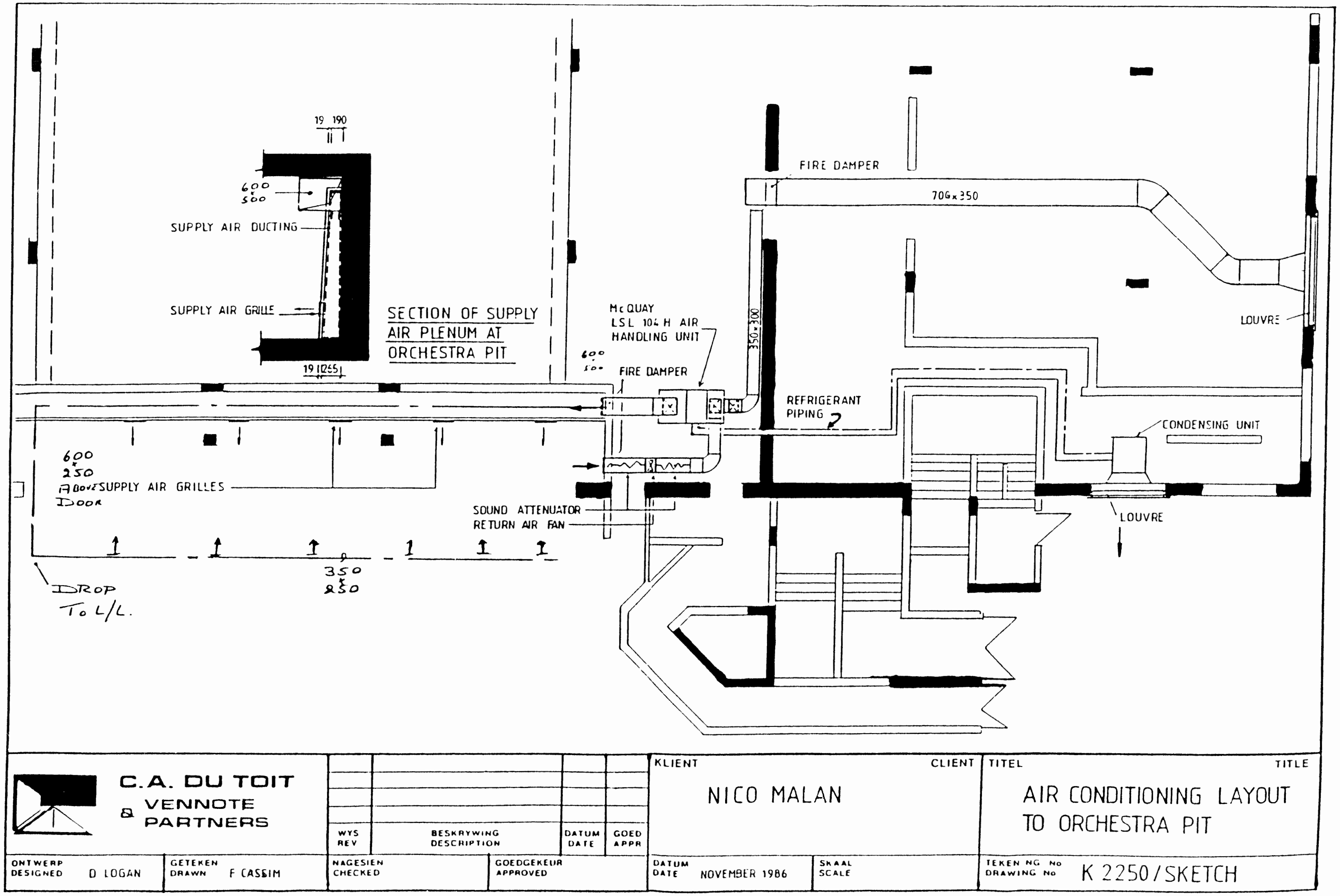


Fig. 1. Plan for a separate air conditioning plant at the Nico orchestra pit (1986)

(Reprinted with permission)

installed for the orchestra pit. A scanner board enables the air-conditioning technician to monitor temperatures throughout the auditorium at the touch of a button. In this way, any rise in temperature can be counteracted by, for example, adjusting the air velocity. This facility is particularly appropriate in an orchestra pit where the effective temperature varies continually from the beginning to the end of a performance.

6. FINAL CONSIDERATIONS

Air-conditioning the orchestra pit is important not only for the comfort and well-being of the musician, but also for the performance potential of his instrument. Wind and string players will experience tuning difficulties should the temperature become extreme. For example, at high temperatures the pitch of a brass instrument will rise while that of a wooden instrument will become lower.

If the level of relative humidity in the pit is below 40%, not only is there a greater risk of bacterial or viral infection, but the integrity of a stringed instruments' wood will also be adversely affected - i.e. the body will begin to crack.[1] Musicians sometimes insert humidifiers into their instruments as a preventive measure.

---

1. CROOME & ROBERTS, P.122

7. SEATING

The professional pit musician spends his entire playing career seated.[1] Therefore it is essential that a comfortable and correct posture is upheld. In this way the risk of vertebral subluxation is also avoided :

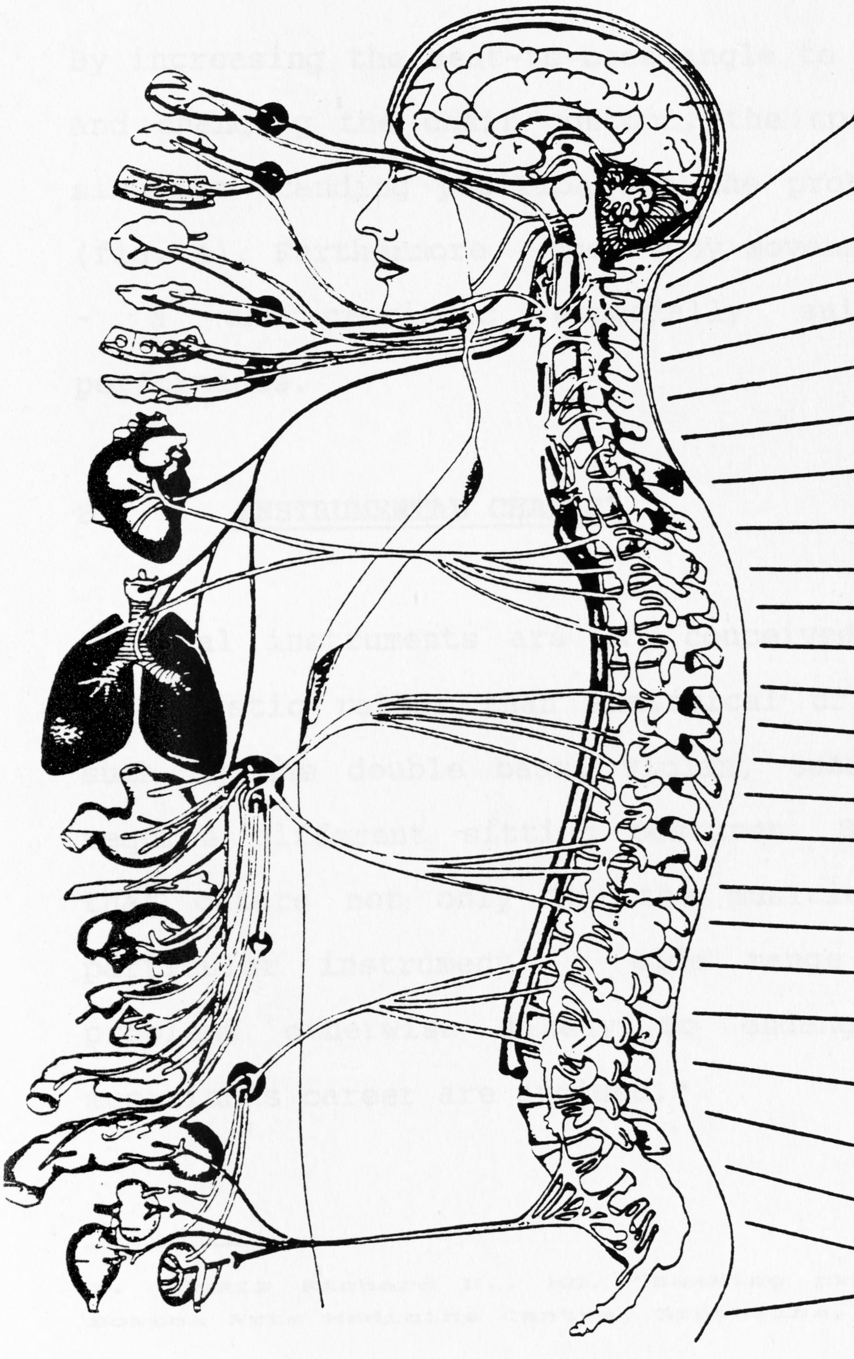
> "All nerves leaving or entering the spinal cord do so through small openings between each vertebra. These nerves go to every organ and system in the body. The nerves can be greatly affected by changes in the vertebral joints. This is known as vertebral subluxation. The vertebral subluxation can result in a host of symptoms (fig.2)."[2]

The chair must shape the vertebral column into the correct sitting posture. When seated, the musician's spine and pelvis should simulate the natural standing position. However, "the human body was not designed to sit with the hips and knees at 90°. ... (In fact,) when the hips are flexed to 90°, the femur (thigh bone) only can rotate 60° in the hip socket. The remaining 30° comes from a posterior or backward rotation of the pelvis" ... resulting in a slumped

---

1. Percussionists are the exception.

2. McKIEVER Dr. Jonathan, "A Chiropractic Guide to Health", Claremont Chiropractic Centre, Cape Town.



VERTEBRAE	AREAS	
1C	Blood supply to the head, pituitary gland, scalp, bones of the face, brain, inner and middle ear, sympathetic nervous system	NECK REGION
2C	Eyes, optic nerves, auditory nerves, sinuses, mastoid bones, tongue, forehead	
3C	Cheeks, outer ear, face bones, teeth, trifacial nerve	
4C	Nose, lips, mouth, eustachian tube	
5C	Vocal cords, neck glands, pharnyx	
6C	Neck muscles, shoulders, tonsils	
7C	Thyroid gland, bursae in the shoulders, elbows	
1T	Arms from the elbows down, including hands, wrists, and fingers, esophagus and trachea	MID BACK
2T	Heart, including its valves and covering, coronary arteries	
3T	Lungs, bronchial tubes, pleura, chest, breast	
4T	Gall bladder, common duct	
5T	Liver, solar plexus, blood	
6T	Stomach	
7T	Pancreas, duodenum	
8T	Spleen	
9T	Adrenal and supra-renal glands	
10T	Kidneys	
11T	Kidneys, ureters	
12T	Small intestines, lymph circulation	
1L	Large intestines, inguinal rings	LOW BACK
2L	Appendix, abdomen, upper leg	
3L	Sex organs, uterus, bladder, knees	
4L	Prostate gland, muscles of the lower back, sciatic nerve	
5L	Lower legs, ankles, feet	
SACRUM	Hip bones, buttocks	PELVIS
COCCYX	Rectum, anus	

Fig. 2. Nerve control of vital organs

(Reprinted with permission)

spinal curve (fig. 3).[1]

By increasing the seat-to-back angle to more than 90 degrees and changing the chair contour, the spine is encouraged to simulate standing position and the problem is thus avoided (fig. 4). Furthermore, upper body movement is not restricted - a characteristic especially suited to orchestral performance.

8. INSTRUMENTAL CHAIRS?

"Musical instruments are ... conceived primarily according to acoustic rather than anatomical criteria."[2] Instruments such as the double bass, violin, tuba and contra bassoon require different sitting postures. By providing a chair that caters not only for the musician but also for his particular instrument, a wide range of musculo-skeletal problems otherwise likely to endanger the professional musician's career are avoided.[3]

---

1. NORRIS Richard N., MD, "Seating problems of Musicians", Boston Arts Medicine Centre, Brookline, U.S.A., 1990, P. 1

2. BENDA Christian, "Is the cello, a problem instrument?", The Strad, Vol. 101, No.1204, Aug. 1990, P. 620

3. MIDDLESTADT S.E., FISHBEIN M, "The prevalence of severe musculoskeletal problems among male and female symphony orchestra string players," Medical Problems of Performing Artists, Vol. 4, No. 1, Mar. 89, P.44

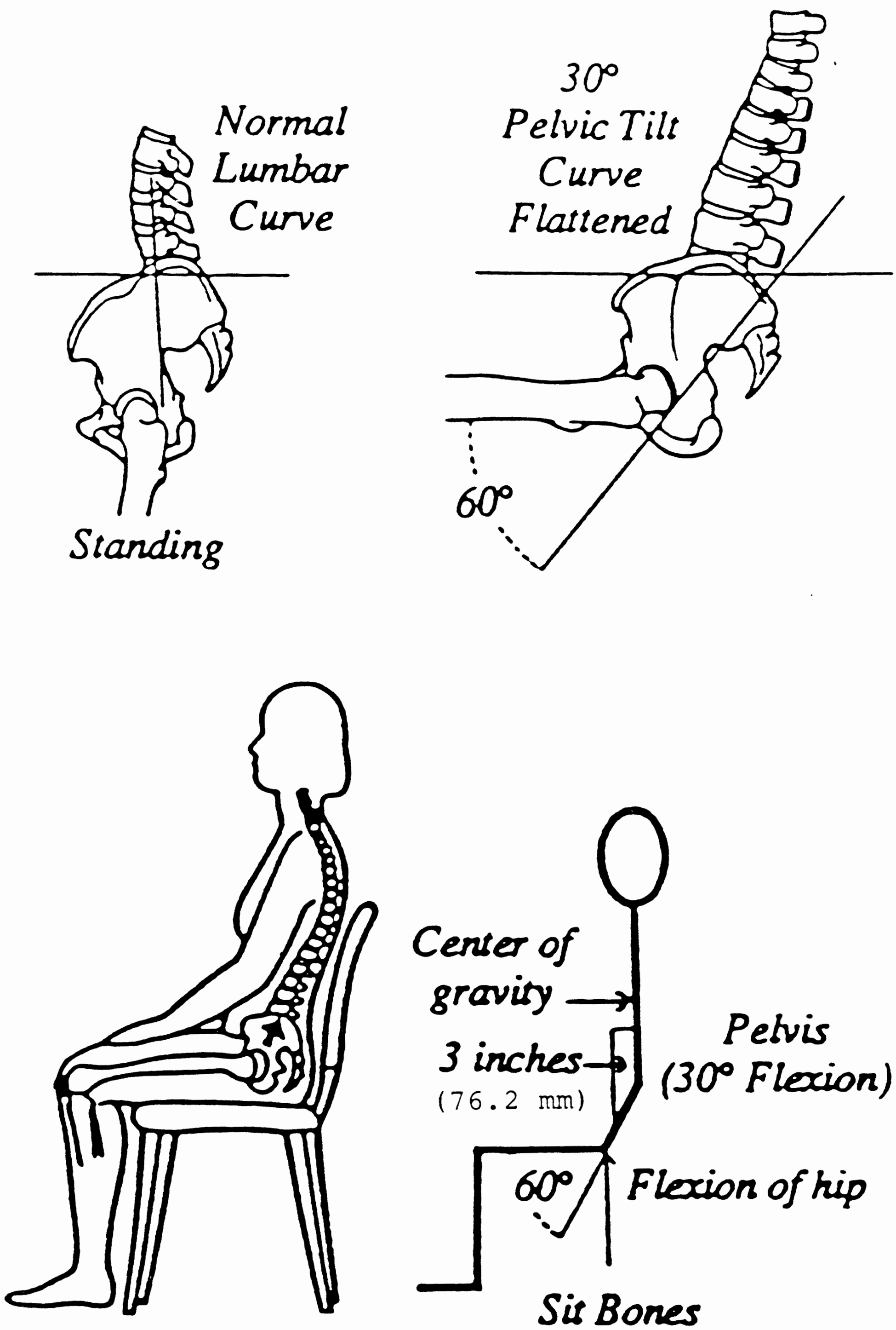


Fig. 3. The effects of sitting with
the hips and knees at 90°

Adapted from Norris, P. 1
(permission applied for)

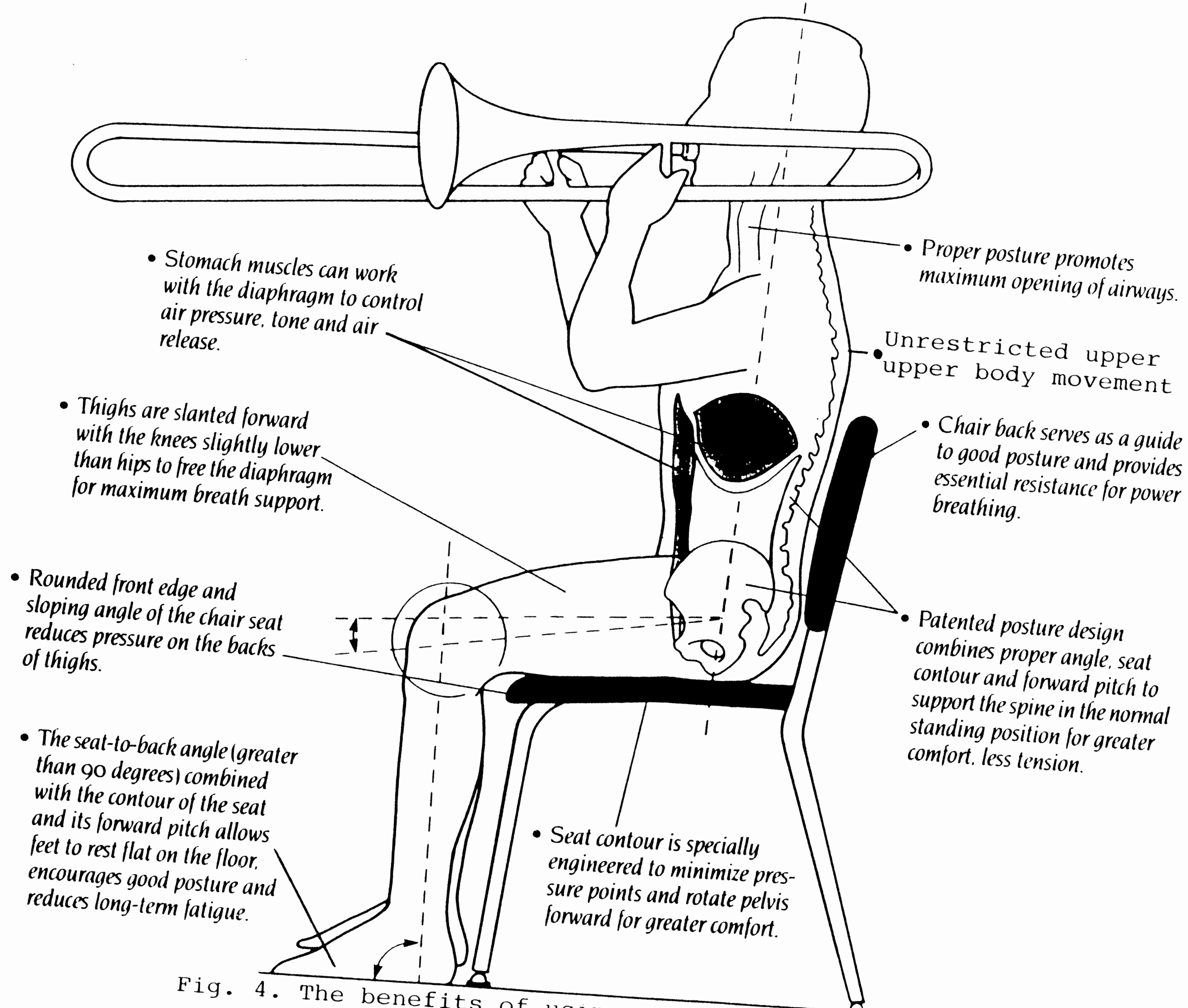


Fig. 4. The benefits of using posture design chairs

Adapted from Wenger Cat. 1992, P. 5

(permission applied for)

The Wenger Corporation, providers of distinctive equipment for music education and the performing arts, manufactures eight different chair types, each with a patented posture design :

> "The natural lumbar curve in the lower back area encouraged by our chair design keeps the vertebrae from pinching disks, thus preventing discomfort and possible long-term health problems. In addition contouring in the seat eliminates pressure points in the buttocks and thighs for better comfort."[1]

The most expensive model, the symphony chair, includes two extra features : there is a hand operated seat angle adjustment control for changing the thigh angle of seat, and an adjustable lumbar pad for additional lower back support. A number of posture chairs and accessories have also been specifically designed for the individual instruments. For example, the cellist's chair is tilted forward an extra 1° for improved playing posture. A "Tuba Tamer" ensures a comfortable performing angle and height, while chairs designed for string bassists and percussionists swivel 170 degrees for easy instrument handling.[2]

---

1. WENGER Corporation, "Music Posture Chairs", Owatonna, Minnesota, 1987/88 Brochure, P. 3

2. WENGER, 1991/92, P. 4-13

9. LIGHTING

> "Foremost in designing a lighting installation is determining the purposes it will serve. Simply applying lighting to a fixed space doesn't work because different needs will likely have to be met, ... Some of the variables that influence choices of light sources and luminaire configurations include the range required lumination levels, brightness control, flexibility in space arrangement, ease of maintenance and service, initial operating and owning costs, overall efficiency of systems, colour and texture of the room materials, compatability with building mechanical systems, compatability with ceiling and architectural details, uniformity and diffusion, use of space and user's requirements and the skills of the designer."[1]

In an orchestra pit, every effort is made to conceal the presence of any form of light. Virtually all surfaces, furniture and attire are black. The only light generated within the pit is from music stands. Such conditions are unavoidable if the audience is to have an undistracted view of the stage. On the other hand, the instrumentalist will require that his music and the conductor are clearly visible.

9.1 SAFETY

A number of factors dictate the limits for compromise. The

---

1. CHISVIN Jack & GOTTESMAN Dan, "The fundamentals of lighting design", Canadian Architecture, Vol. 33, No. 4, Apr. 1988, P. 61

first is safety. At the Nico Malan, 220 volt electric cables run randomly throughout the pit.[1] The continual changing of the orchestra seating plan in any pit may result in wear and tear of these cables. However, the risk of electric shock has been reduced at the Nico Malan by installing an earth leakage device, i.e. a trip-system. Such devices are problematic in that there is the possibility that the system may trip unnecessarily during a performance.[2] By supplying a low voltage current (12 V), both of the above problems are avoided but the choice of lamp is then limited unless a transformer is supplied with each music stand.[3]

9.2 EXCLUSION OF EXTRANEOUS NOISES

> "Of the many services that must be considered when planning the lighting of an interior, acoustics is often the one that makes the most demands on the designer."[4]

---

1. Depending upon the size of the orchestra, numerous extension cables, complete with six socket "home-made" outlet boxes, supply electricity to the music stands.

2. Interview (11.08.1992) : Mr. P. de Swardt, "regular safety inspections are carried out".

3. HART Alan, "Flexibility offered by low voltage cable lighting systems", Architects' Journal Focus, Vol. 1, No. 7, Oct. 1987, P. 12-13

4. PHILLIPS Derek, Lighting in Architectural Design, McGraw Hill, New York, 1964, P. 213

Lights or transformers can produce noise levels above the desired backround ambient. For example, fluorescent lights could not be used in the Nico Malan orchestra pit because they produce a noise level of 35 dBA, which is 5 dBA above the desired backround ambient required for the auditorium.[1]

9.3 CONTRAST

Contrast is "the subjective assessment of the difference in appearance of two parts of a field of view seen simultaneously or successively."[2] Depending upon the intensity of the light, the musician may find the contrast between the reflection of light from the sheet music and the darkness of the surrounding environment uncomfortable. Such problems are apparent in the Nico Malan orchestra pit. In fact musicians sometimes remove one or two of the three music stand light bulbs in an attempt to reduce the discomfort. Because contrast is a subjective element, this problem can only be alleviated by installing a dimmer-switch on each music stand.[3]

---

1. Interview (27. 08. 1992) : P. Conradie, electrical engineer, C A du Toit & Partners.

2. DE BOER J. B. & FISCHER D, Interior Lighting, Macmillan Press Ltd., London, 1978, P. 316

3. 100mm by 50mm dimmer-switches are relatively inexpensive electrical appliances (approximately R50 in 1992).

9.4 GLARE

There are two types of glare : disability glare and discomfort glare. The latter causes discomfort without necessarily impairing vision, while the opposite is true for disability glare.[1] Intense light from other music stands or stage lighting causes discomfort especially where the direct light has not been concealed properly. The degree of discomfort will depend upon the brightness of the source.

> "Discomfort glare is derived from what is virtually a naked tungsten filament (domestic) lamp, close to the line of vision, and seen against a darker backround. ... some disability may also be present owing to the specular reflection from glossy paper, which reduces the contrast on the printed page."[2]

One method of alleviating the discomfort problem is to adopt a similar approach to that used for museum lighting where the light is set back and directed onto the music within a 45° angle. In this way the light is evenly spread over the entire face of the music rather than the diffused distribution that occurs when the source is positioned directly above the music as at the Nico Malan pit.

---

1. HENDERSON S.T. & MARSDEN A.M, Lamps and Lighting, 2nd ed., Edward Arnold Ltd., London, 1972, P. 33

2. PHILIPS, P. 39

LAMP TYPES

10.1 DISCHARGE LAMPS

Basically there are only two types of lamp suitable for music stands : the fluorescent or the incandescent lamp. Discharge lamps are used mainly for industrial applications. They are normally installed at high ceiling levels and are not dimmable. The range includes high-pressure sodium, mercury, xenon and metal halide lamps. The latter two have a power rating of between 2,000 and 10,000 watts.

10.2 FLUORESCENT LAMPS

Fluorescent lamps are dimmable, however a transformer is required for orchestra pits using low voltage electric supply. The smallest dimmable fluorescent lamps are 600 mm, but "they prove to be financially impossible" in a low voltage pit environment.[1] Miniature 12 volt fluorescent lamps (PL or 2D types) are available, however they are not dimmable.

---

1. Interview (27.08.1992) : P. Conradie.

10.3 INCANDESCENT LAMPS

These type of lamps are used domestically, for example at the bedside. Incandescent lamps are noise-free and dimmable. In 1987, tungsten halogen lamps were introduced. These are miniature, low voltage, dimmable, noise-free incandescent lamps (25 or 50 watt). Their cost, relative to the other lamp types (except domestic incandescents), is inexpensive (approximately R20.00 in 1992). The tungsten halogen lamp is therefore the most suitable compromise for a comfortable orchestra pit environment.

CONCLUSION

The purpose of this thesis has been to examine the eternal verities and dilemmas of orchestra pit design. It is intended that such an exegesis will benefit not only the musician's own understanding of his working environment, but might also serve as a guide to theatre planners. To my knowledge there is no single source that discusses the sub-stage environment from a musical/technical point of view.

Perhaps the most important discovery that emerged from the numerous interviews held during the past two years was the apparent lack of understanding on the part of the designer (and his consultants) for the orchestra pit user. It is my understanding that of the various design problems delineated, many could have been avoided had there been direct contact between the two. Indirect and thus imperfect knowledge of the musician's basic performance criteria not only impairs, but puts the potential for successful design at risk.

From a personal standpoint as an orchestra pit musician, my conclusions are disappointing in that the fundamental design of the pit is founded upon compromises rather than ideals. The musician is in many ways a victim of circumstance. Practically every decision about his workplace is taken globally rather than distinctly - acoustics, dimensions, lighting, seating positions, attire and so forth.

However there is hope, not only for future, but also for existing orchestra pits. The alterations to the Nico Malan Opera House have clearly demonstrated that it is possible successfully to improve conditions for established opera pits through, for example, acoustic tuning, structural modification or air conditioning installation. In April 1992, the Nico Malan Theatre orchestra pit[1] was also enlarged, further demonstrating that architecture, in this context, does not have to be regarded as irreversible history.

Throughout this study, many colleagues have queried what my recommendations for future pit designs would be. My answer has been consistent : it depends entirely upon the function of the theatre for which one is designing. If I were to choose the single most important criterion for successful sub-stage design it would be quality of sound : determining the appropriate coupling factor is therefore fundamental.

For dance, where the orchestra dominates the whole aural perception, I would recommend an open or partially closed orchestra pit, depending upon the repertoire of the music performed. Certainly for most types of opera an overhang is

1. As distinct from the Nico Malan Opera orchestra pit.

needed for balance and control. Wagner closed his pit at Bayreuth by 75% and this is extreme but nonetheless successful within the context for which it was created. However, most pits are designed for general-purpose theatres where a balance between the clarity of a dance acoustic and the blend of a romantic opera acoustic is required. In my opinion a suitable overhang depth for general-purpose design would be between 25% - 33% of the total floor area.[1]

It must be stressed however, that the above recommendation applies only to the acoustic rather than the overall design of the orchestra pit. There are numerous other variables that need consideration, e.g. the psychological gap, the floor area, the orchestra size, the seating layout and the conductor's angle of vision. Throughout this thesis I have generally avoided making detailed recommendations because the options are so varied - design criteria ought to stem from individual needs rather than the other way around.

Orchestra pits should maybe not be compared at all; simplified schemes or models give a framework for comparison on a prompt but perhaps overly facile basis. The fundamental problem with pit design is not so much lack of knowledge as

---

1. Of the thirteen non-open pits Beranek measured, overhang depths ranged from 6% to 75% of the total floor area but averaged 32%. BERANEK, P.560

it is lack of communication among specifiers and planners. Comparisons are valid up to a point; the rest hangs upon the quality of communication among musician, manager and designer. Architectural and acoustic theory cannot alone specify the criteria for a successful theatre at this stage in technology and art.

Some designers are primarily "influenced by how things look".[1] While aesthetic appearance is unquestionably an important facet of auditorium planning, practicality and function ought to dictate the basis of the design. Modern society seems to place much emphasis upon material and physical impression, "image", so much so that the artistic element may even become secondary. Establishment of functional priorities at the outset helps ensure that design defects do not become apparent too late in the process. Yet the final arbiter of success remains the most complex : aesthetic sound for audience and performer.

---

1. BARNETT Jack, architect, interview : 09.03.1992.

BIBLIOGRAPHY

ALLEN John P., A History of the Theatre in Europe, Barnes & Noble Books, London, 1983.

ALOI Roberto, Architetture per lo spettacolo, Hoepli, Milan, 1958.

ANGUS Thomas C., The Control of Indoor Climate, Pergamon Press, Oxford, U.K., 1968.

ATHANASOPULOS Chrisos Giorgos, Contemporary Theatre Evolution and Design, John Wiley & Sons, New York, 1983.

BACKUS John, The Acoustical Foundations of Music, Murray, London, 1970.

BAGENAL Hope, Practical acoustics and planning against noise, Methuen, London, 1942.

BARRICK Adrian, "Larson cuts opera house by half to ease costs", Building Design, No. 1039, June 7 1991.

BARRON Michael, "The Subjective Effects of First Reflections in Concert Halls - the need for lateral reflections",Journal of Sound and Vibration, Vol. 15, No. 4, 1971.

BENADE Arthur H., Fundamentals of Musical Acoustics, Oxford University Press, New York, 1976. See also, rev. ed., Dover Publishers, Nov. 1990.

BENDA Christian, "Is the cello, a problem instrument?", The Strad, Vol. 101, No. 1204, Aug. 1990.

BERANEK Leo L., Acoustic Measurements, John Wiley & Sons, New York, 1950.

BERANEK Leo L., Music, Acoustics & Architecture, John Wiley & Sons, New York, 1962, reprinted Krieger, Huntingdon, New York, 1979.

BOOTH Kenneth, Dictionary of Refrigeration and Air Conditioning, Applied Science Publishers, London 1970.

BRADLEY J.S., "Acoustical comparison of three theatres," Journal of the Acoustical Society of America, Vol. 79, No. 6, June 1986.

BURRIS-MEYER H. & COLE E.C., Theatres and Auditoriums, 2nd ed., Rheinhold Publishers, New York, 1975.

BUTTERY Helen, "Fantasy or Fact?" (sick building syndrome), Interior Design, Nov. 1987.

CHISHOLM Fiona, "London replica of The Space takes off," Cape Times, Cape Town, May 27, 1992.

CHISVIN Jack & GOTTESMAN Dan, "The fundamentals of lighting design," The Canadian Architect, Vol. 33, No. 4, Apr. 1988.

CORRY Percy, Community Theatres, Pitman Publishing, London, 1974.

CREMER Lothar & MUELLER Helmut, Principles and Applications of Room Acoustics, vols. 1 & 2, Applied Science Publishers, London, 1982.

CROOME Derek J. & ROBERTS Brian M., Air Conditioning and Ventilation of Buildings, 2nd ed., Pergamon Press, Oxford, U.K., 1981.

EDWARDS Nicholas, "The new generation in acoustics," The Musical Times, Vol. 133, No. 1789, March 1992.

FABER Oscar, Heating and Air Conditioning of Buildings, 5th rev. ed. by Kell J. R. and Martin P. C., Architectural Press, London, 1971.

FAITH William L., Air Pollution Control, John Wiley & Sons, New York, 1959.

FENNELL Frederick, Time and the Winds, Leblanc Publications, Wisconsin, U.S.A., 1954.

FISHER D, & DE BOER J.B., Interior Lighting, Macmillan Press Ltd., London, 1978.

FLICKINGER Roy C, The Greek Theatre and its Drama, University of Chicago Press, Chicago, 1918, 4th ed., 1960.

FLYNN John E., Architectural Interior Systems; lighting, air conditioning and acoustics, Van Nostrand Publishers, New York, 1970.

FORSYTH Michael, Buildings for Music, The MIT Press, Cambridge, Massachusetts, U.S.A., 1985.

FREEDLEY George, A History of the Theatre, Crown Publishers, New York, 1941.

GARNIER Charles L'Opera, Hachette (publishers), Paris, 1880.

GEBHARD Elizabeth, "The Form of the Orchestra in the Early Greek Theatre", Hesperia, Vol. 43, 1974.

GISHFORD Anthony, (Ed.) Grand Opera : The Story of the World's leading Opera Houses and Personalities, Weidenfeld & Nicolson Inc., London, 1972.

GRANDJEAN E, Sitting Posture, Taylor & Francis Ltd., London, 1969.

GREENBIE Barrie, (in) The Ideal Theatre : Eight Concepts, American Federation of Arts, Tri Arts Press Inc., New York, 1962.

GRETRY Andre, Memoirs ou Essais sur la musique, iii, Paris, no publisher, 1789.

HAM Roderick, Theatre Planning, The Architectural Press, London, 1972.

HARTNOLL Phyllis, The Oxford Companion to the Theatre, 3rd ed., Oxford University Press, U.K., 1967.

HARTNOLL Phyllis, A Concise History of the Theatre, Thames & Hudson Publishers, London, reprinted 1969.

HENDERSON Stanley, MARSDEN A.M. Lamps and Lighting, 2nd ed., Arnold, London, 1972.

HUNT Edgar (Ed.) "Music Stands", The Recorder and Music Magazine, Vol. 8, No. 9, March 1986.

HUNT Frederick V., Origins in Acoustics ; the science of sound from antiquity to the age of Newton, Yale University Press, New Haven, 1978.

INGERSLEV Fritz, Acoustics in Modern Building Practice, Architectural Press, London, 1952.

IZENOUR George C., Theatre Design, McGraw-Hill Publishers, New York, 1977.

IZENOUR George C., "The ancient Roman roofed theatre", Perspecta, No. 26, 1990.

IZENOUR George C., "The multiple-use theatre", Theatre Design & Technology, Vol. 28, No. 1, Winter 1992.

JOHNSON Russell, "Orchestra Pits", Theatre Design & Technology, Vol. 15, No. 3, Fall 1979.

JONES William P., Air Conditioning Engineering, 2nd ed., Whitstable Litho Ltd., Kent, U.K. 1975.

JOSEPH Steven, Actor & Architect, Manchester University Press, U.K., 1964.

KANDELL Leslie, "Funding Opera An Angel's Way ...," Opera News, Vol. 51, No. 10, Jan. 31, 1987.

KEELING Stuart, "How to make the best use of today's lighting", Energy in Buildings, Oct. 1990.

KEET Wilhelm Brochure : Nico Malan Theatre Centre, 1971.

KEET Wilhelm "The influence of Early Lateral Reflections on the Spatial Impression", The 6th International Congress on Acoustics, Tokyo, August 21-28, 1968.

KEYS Peter & MOWBRAY Trevor, Progress report : Sydney Opera House, Architecture in Australia, Oct.1968.

KIEVMAN Louis, "Listening-Hearing," The Strad, Vol. 101, No. 1207, Nov. 1990.

KING Guy R., Basic Air Conditioning, Nickerson & Collins Co., Chicago, U.S.A., 1965.

KINSILA Edward B., Modern Theatre Construction, Chalmers Publishing Company, New York, 1917.

LANGHOFF Andreas, "Interpreting Acoustic Curves," The Strad, Vol. 103, No. 1222, Feb., 1992.

LAWRENCE Anita, Architectural Acoustics, Applied Science Publishers, London, 1970.

LEACROFT Richard & Helen — Theatre and Playhouse, Methuen Inc., London, 1984.

LEVIN Hal & TEICHMAN Kevin, "Indoor air quality - for architects", Progressive Architecture, Vol. 72, No. 3, Mar. 1991.

LOEWENBERG Alfred, Annals of Opera 1597 - 1940, Societas Bibliographica, Geneva, Switzerland, 1955.

MANDAL A. C., The Seated Man, Dafnia Press, Copenhagen, 1985.

MARSHALL Arthur, "A Note on the Importance of Room Cross-section in Concert Halls", Journal of Sound and Vibration, Vol. 5, No. 1, 1967.

MARSHALL Arthur, "Levels of Reflection Masking in Concert Halls", Journal of Sound and Vibration, Letters to the editor, Vol. 7, No. 1, 1968.

McCUE Edward, "Room Acoustics and the Orchestral Hornist," The Horn Call, Vol. 19, No.1, Oct., 1988.

McKIEVER Jonathan, "A Chiropractic Guide to Health" by Claremont Chiropractic Centre, Cape Town.

MIDDLESTADT S.E. & FISHBEIN M., "The prevalence of severe musculoskeletal problems among male and female symphony orchestra string players ", Medical Problems of Performing Artists, Vol. 4, No. 1, Mar. 1989.

Miller John & JEFF Charles, "Noise 1 : The risks", The Architects' Journal, Vol. 187, No. 5, Feb. 3, 1988.

Miller John & JEFF Charles "Noise 2 : The remedies," The Architects' Journal, Vol.187, no. 6, Feb. 10, 1988.

NICOLL Allardyce, The Development of the Theatre, 3rd ed., George Harrap & Co. Ltd., London, 1966.

NORRIS Richard N., "Seating Problems of Musicians", Boston Arts Medicine Centre, Brookline, U.S.A.

ORREY Leslie, (Ed.) The Encyclopedia of Opera, Pitman Publishing Ltd., London, 1976.

PARKIN Peter H. & ALLEN W.A., "Royal Festival Hall", Special issue: The Architectural Review, Vol. 109, No. 654, June 1951.

PARKIN Peter H., Acoustics, Noise and Buildings, 3rd ed., Faber, London, 1969.

PEVSNER Nikolaus, A History of building Types, Thames and Hudson, London, 1976.

PHILLIPS Derek, Lighting in Architectural Design, McGraw Hill, New York, 1964.

PILBROW Richard, Stage Lighting, 3rd ed., Macmillan, New York, 1976.

PYLE Robert, "Acoustical Reverberations", The Horn Call, Vol. 18, No.1, Oct. 1987.

PYLE Robert, "Terminology and History of Architectural Acoustics," The Horn Call, Vol. 19, No.1, Oct., 1988.

RAMSEY Basil, "Editorial Jottings," The Musical Times, Vol. 132, No. 1778, April 1991.

RANDEL Don M., "Orchestra", The New Harvard Dictionary of Music, The Belknap Press of Harvard University Press, Cambridge, U. S. A., 1986.

REEVES Geoff "Lighting the workplace for comfort and productivity", Architecture Australia, Vol. 77, No. 5, July 1988.

RIEDEL Scott R., "Acoustics in the Worship Space IV", The Diapason, VOL. 78, No. 5, May 1987.

RIEDEL Scott R., "Acoustics in the Worship Space V", The Diapson, Vol. 79, No. 4, Apr. 1988.

ROONEY Dennis, "Resounding Restoration", The Strad, Vol. 98, No. 1171, Nov. 1987.

ROONEY Dennis "Isaac Stern speaks about the `new' Carnegie Hall", The Strad, Vol. 98, No. 1171, Nov. 1987.

RUSKIN John, The Stones of Venice, 4th ed., George Allen Publishers, Kent, U.K., 1851.

SABINE Wallace C., Collected Papers on Acoustics, Harvard University Press, Cambridge, U. S. A., 1923.

SADIE Stanley, (Ed.) "Orchestra", The New Grove Dictionary of Music & Musicians, Vol. 13, Macmillan Publishers Ltd., London, 1980.

SCHAUDINISCHKY, Leo H., Sound, Man and Building, Applied Science Publishers, London 1976.

SCHUBERT Hannelore, The Modern Theatre ; architecture, stage design, and lighting, Pall Mall Press, London, 1971.

SHERRATT Alan F., Air conditioning & energy conservation, Mackay Ltd., Kent, U.K., 1980.

SILVERMAN Maxwell, Contemporary Theatre Architecture, The New York Public Library, Charles Francis Press, New York, 1965.

SMITH Barbara J., Acoustics, Longman Publishers, London, 1971.

SMITH Patrick J., "Funding Opera ... Uncle Sam's Way," Opera News, Vol. 51, No. 10, Jan. 31, 1987.

SOUTHERN Richard, "The History of Adaptable Theatres", Conference : The Association of British Theatre Technicians, Adaptable Theatres, Pindar, Scarborough, U.K., 1962.

STRATELAK Nadia, THE MUSIC INDEX, Harmonie Park Press, Michigan, U.S.A., 1949 - present.

TEMPLETON Duncan & SAUNDERS David, Acoustic Design, Architectural Press, London, 1987.

UNGERSON Julius, "Both Sides of the Pit", The Strad, Vol. 88, No. 1055, Ch. 7, March 1978.

VAUGHAN Denis, "Music and Building", The Musical Times, Vol. 127, No. 1721, Aug., 1986.

VAUGHAN Denis, "The full potential in orchestral sound", The Musical Times, Vol. 130, No. 1757, July, 1989.

WAGNER Richard, Der Ring des Nibelungen (Eng. trans.), Faber Music, 1977.

WECHSBERG Joseph, Music critic, The New Yorker, August 18, 1956.

WENGER CORP., Distinctive Equipment for Music Education and the Performing Arts, Owatonna, Minnesota, (Elwyn C. Peterson - Director of International Sales).

WESTON Herbert C., Sight Light & Work, 2nd ed., H. K. Lewis & Co. Ltd., London 1962.

WOHR M., "The Bayreuth Festspielhaus - reality and ideality comments on sound broadcast transmissions," Rundfunktechnische Mitteilung, Vol. 27, No. 2, Mar.- Apr. 1983.

XU Yaying "Listening to sound, the criteria of perception", Techniques & Architecture, No. 389, Apr. 1990.

YOUNG Robert W., "Sound absorption in air in rooms", Journal of the Acoustical Society of America, Vol. 29, No. 2, 1957.

No author or editor cited "Orchestra Pits", The Architects' Journal (Information Library), Information sheet 1267, Vol. 140, No. 4, 22 July, 1964.

APPENDIX 1

AKOESTIPLAN
AKOESTIESE RAADGEWERS — ACOUSTICAL CONSULTANTS

J. F. BURGER. Pr. Ing., B Sc (Ing.) Ph D
W. de V. KEET, M Sc., Ph D

TEL. 47-3641

Rydal 132,
The Hillside 320,
Lynnwood,
Pretoria.
0081

Our reference: AH/79/45

12th October, 1979.

REPORT ON ACOUSTICAL TESTS AT NICO MALAN OPERA COMPLEX

1. INTRODUCTION

Akoestiplan was asked to assist with acoustical investigations at the Nico Malan Opera Complex. These included:

(a) Resetting the Proscenium Reflectors.
(b) Noise Measurements in the Theatre.
(c) Noise Measurements in the Opera Auditorium.
(d) Sound Propagation Measurements in the Opera Auditorium with various configurations of the Orchestra Pit.
(e) Listening Tests with the above configurations.
(f) Listening Tests at Performances with two configurations of the Orchestra Pit, viz. for Ballet and Opera.

This report deals with the results and conclusions of these tests, and makes recommendations regarding improvements to acoustical conditions.

2. RESETTING THE PROSCENIUM REFLECTORS

In the course of the years, these reflectors had become misaligned at various stages when the side slots had been put to other uses.

The reflectors were realigned in accordance with the original geometry as specified in CSIR's letter of 5.11.1971, with figure attached. Mirrors were fixed to the centres of the reflectors and they were realigned by means of a light source moved to the correct position for each reflector, the positions having been calculated previously.

The position/......

The position of each reflector was marked both in azimuth and elevation by means of a scriber. It is proposed tc drill locating holes in the pipes and to use the wingbolts as locating pins so that the reflectors may be accurately positioned. We suggest using additional wingbolts for this, otherwise the chances are that the reflectors will become misaligned during the drilling process. A safer procedure might be to tack-weld the pipes after careful position checks.

3. NOISE MEASUREMENTS IN THEATRE

Measurements on air-conditioning noise were carried out in the Theatre, using a Brüel and Kjaer precision sound level meter and octave filter set type 2203/1613. The results are given in Table I, together with measurements made during the commissioning period.

TABLE I. NOISE MEASUREMENTS IN THEATRE

Octave band centre frequency (Hz)	63	125	250	500	1k	2k	4k	A	NR
SPL on 5.10.79 (dB)	51	45	40	34	32	24,5	18	37	32
SPL on 22.4.71 (dB)	50	43	33	28	23	16	13,5	32	24
Difference (dB)	1	2	7	6	9	8,5	4,5	5	8

3.1 Discussion

(a) It is clear that the noise level has increased appreciably, especially in the middle frequencies.

(b) The noise seems to be caused by excessive air velocity through the supply grilles.

4. NOISE MEASUREMENTS IN OPERA AUDITORIUM

These measurements were carried out on the balcony, where the noise level is highest, using the equipment mentioned above. The results are given in Table II, together with measurements made during the commissioning period.

TABLE II/.......

TABLE II. NOISE MEASUREMENTS IN OPERA AUDITORIUM

Octave band centre frequency (Hz)	63	125	250	500	1k	2k	4k	A	NR
SPL on 5.10.79 (dB)	50	47	43	37,5	35	28	18,5	41	35
SPL on 21.4.71 (dB)	49	44	34,5	30	28	23,5	21	34	28
Difference (dB)	1	3	8,5	7,5	7	4,5	-2,5	7	7
SPL on 21.4.71 (roof fans off) (dB)	41	36	32	26	22,5	15	10,5	29	23

4.1 Discussion

(a) The noise increase is of the same order as that in the theatre.

(b) The anomaly at 4 kHz is probably due to the fact that on 21.4.1971 the roof extract fans were still causing a lot of noise. This was later rectified. This means that the actual increase of noise is probably even larger than indicated, as can be inferred from the last row of figures in Table II. Unfortunately no measurements were made immediately after the roof extract fans had been treated. (See also our report of 6th October, 1975, ref. AH/73/82, pages 5 and 6.)

5. SOUND PROPAGATION MEASUREMENTS (OPERA AUDITORIUM)

The effect of removing the orchestra pit railing was measured, using a pink noise source in the pit. The floor was at the standard level and the noise source was located 4 m left of centre and 2 m from the curved pit wall. The source was used with low frequencies filtered out, and measurements were made in various seat positions, using the precision sound level meter with A weighting network. The results are given in Table III.

TABLE III/.....

TABLE III. EFFECT OF REMOVING ORCHESTRA PIT RAILING

Position	Levels with railing (dBA)	Levels without railing (dBA)	Differences (dBA)
A30	81	84m5	3,5
B4	77	79	2
B18	79	81	2
B33	80,5	82	1,5
C36	79,5	81,5	2
D5	77,5	78,5	1
D19	79	80	1
D37	79	80,5	1,5
E38	80	81	2
G7	76,5	78,5	2
G22	77	78,5	1,5
G40	77,5	79	2
J11	77	78,5	1,5
J24	78	79	1
J39	77,5	79	2
M12	77	78,5	1,5
M27	76	78	2
M40	77	79	2
M49	78,5	79	0,5
O7	76	77,5	1,5
O27	76	77,5	1,5
O44	77,5	78	0,5
Average	77,9	79,5	1,6
Standard deviation	1,4	1,7	0,3

5.1 Discussion

(a) Removing the railing causes a slight increase in sound level from the pit.

(b) Removing the railing does not affect the evenness of sound distribution appreciably.

(c) In accordance with diffraction theory, it is expected that the effect of removing the railing will be most noticeable at high frequencies, and will be more marked the closer the sound sources are situated to it. This was borne out in subsequent listening tests.

6. LISTENING TESTS WITH AND WITHOUT RAILINGS

The following configurations were tested:

(a) High floor, standard orchestra arrangement, with railings.

(b)/......

(b) As (a), without railings.

(c) Standard floor level, standard orchestra arrangement, without railings.

(d) As (c), but orchestra arranged for ballet (strings grouped around conductor, woodwinds on left side, brass and percussion on right side).

For all these tests the air-conditioning was switched off, as the noise interfered with subjective judgements due to its distracting effect. The stage loudspeakers were also switched off. For each configuration listening tests were carried out throughout the auditorium as well as on the stage, while the orchestra played extracts of operatic as well as ballet music.

The impressions may be summarised as follows:

(i) Removing the railings caused a pronounced improvement in orchestra sound. The orchestra sounded fuller and the sound had more presence. This was especially noticeable for the strings.

(ii) Lowering the pit floor improved the resonance and blend, but reduced the string presence somewhat, especially in the middle areas of the main floor. (Rows J to M.)

(iii) Rearranging the orchestra to the ballet configuration brought about several remarkable improvements. Firstly, the string presence was restored to an extent almost equalling that of the raised floor. Secondly the tone quality and balance of the orchestra was improved. Thirdly the contact with the stage was greatly improved, both for the strings as well as for the winds. This was perhaps the most remarkable effect, the more so since it was unexpected.

7. LISTENING TESTS DURING PERFORMANCES

One performance of "Swan Lake" was attended, and two of "Nabucco". Seats were changed during intervals. For Swan Lake seats were obtained on the main floor, in rows G, K and O, while for the opera performances seats were obtained for the balcony as well.

The impressions gained may be summarised as follows:

7.1 Ballet

(a) Good resonance, balance and blend throughout.

(b) Row G. Rich, full sound, good string presence, good bass, good spatial impression.

(c) Row K. Sound somewhat thinner, less string presence, less bass, less spatial impression.

(d)/....

(d) Row O. General quality between that of G and K.

7.2 Opera

(a) General impressions

(i) Voice quality good throughout.

(ii) Balance between singers and orchestra good throughout.

(iii) Orchestra sound rather dry and unresonant. Blend between instruments not as good as for ballet. String tone generally better.

(b) Impressions in different seats

The variation in orchestra sound with position was basically the same as for ballet as far as the main floor was concerned. On the balcony there was more fullness and spatial impression, but less than experienced at previous visits to the auditorium. This was most probably due to the fact that the high noise level on the balcony masked the reverberant sound to a large extent.

8. RECOMMENDATIONS

8.1 Air conditioning noise (Opera and Theatre)

The noise levels in both spaces are excessively high, and steps should be taken to reduce them, since the noise seriously reduces the quality of performances. The noise is most likely caused by excessive air flow, and a logical first step would be to check the air velocities and re-balance the system. Once this has been done, noise measurements can be made again.

8.2 Proscenium reflectors

These should be permanently fixed in position as described above.

8.3 Carpet

At discussions between members of CAPAB, the architects, Mr du Toit and myself, the suggestion was put forward that the carpet in the opera auditorium should be removed to reduce sound absorption and improve resonance. We would like to support this suggestion. The best effect will be obtained by removing the carpet entirely and replacing it with a hard, sound reflecting material. If wood is used, it must be fastened to the screed without an air space. The second best effect will be obtained by leaving the carpet between the seats and removing it everywhere else. A slight improvement will be obtained by leaving the carpet but removing the underfelt. Considering the amount of work involved, it will hardly be worthwhile.

8.4 Seats

Another way of improving resonance, would be by making the seat backs and bottoms reflective, e.g. by covering them with plywood. For the sake of appearance, the fabric covering may be retained, provided that it is glued directly to the plywood without foam in between.

8.5 Stage loudspeaker

These speakers, which are currently used to improve contact between the stage and the orchestra pit, cause distortion and colouration. They should be replaced with high quality loudspeakers.

8.6 Orchestra pit

The best sound was obtained with:

(a) The standard floor level;
(b) the orchestra arranged as for ballet;
(c) the pit railings removed.

This configuration also gave the best contact between pit and stage. It is very probable that with this configuration, stage loudspeakers will not be required except for special sets which cause excessive screening.

We would like to recommend that the above configuration be used throughout. The present railings could be replaced with a combination of wrought iron railings with sound transparent curtaining behind, as used in many overseas opera auditoria. If problems are experienced with light spill through the curtain, a double curtain with airspace between could be used, provided that both membranes are still porous and not heavier than about 0,2 kg/m^2 each.

Alternatively, a system of louvres could be used, as employed for the top cover of the pit at Bayreuth. Care will have to be taken to avoid unpleasant slot resonances. A possible configuration is shown in Figure 1.

9. LIGHT BRIDGE (OPERA AUDITORIUM)

The forward light bridge is left permanently open, in spite of

the/.....

the fact that panels have been provided to close off areas not in use. This is a serious drawback, since this is the most important ceiling reflector, being closest to the sound sources. The gap in this reflector is most probably responsible for the deterioration in orchestra sound quality between rows J and M, as well as reduced resonance due to ceiling absorption.

We would recommend closing this section permanently, and either moving the lights further back, or using an open bridge. If a permanent closed bridge is to be installed, we should be consulted, as this will require modifications to the ceiling

10. CEILING PERFORATIONS

Considerable absorption of sound is caused by sound leakage through light fittings. These should be replaced by more suitable types, e.g. WILA type 26934 or type 27104.

11. CONCLUSIONS AND SUMMARY

(a) The acoustical quality of both auditoria will be greatly improved by reducing the air conditioning noise to acceptable levels (33 dBA, NR 25). The noise not only masks soft speech and music sounds, it also masks reflected sounds, thereby reducing perceived resonance, spatial impression and fullness of sound.

(b) Resonance in the opera auditorium should be improved by removing unnecessary absorption. This can be done by modifications to the carpet as well as to the seats, and by closing holes in the ceiling wherever possible, especially the front section, which is the most important ceiling reflector.

(c) The sound from the orchestra pit can be greatly improved by replacing the existing railing with a sound transparent one, using the floor at its standard level, and using the desk arrangement as for ballet performances.

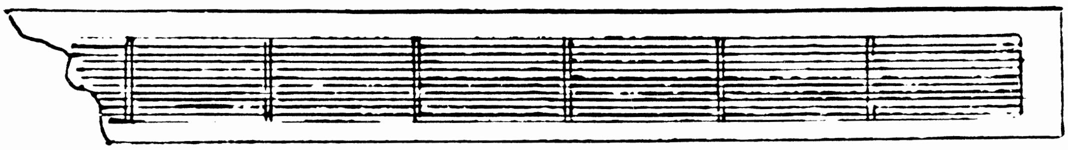
(d) It is expected that problems with the orchestra pit will be less pronounced if the general resonance in the auditorium can be improved, so the logical sequence would be to remove absorption first, and then reassess the situation.

(e) We will gladly give assistance with the implementation of these recommendations.

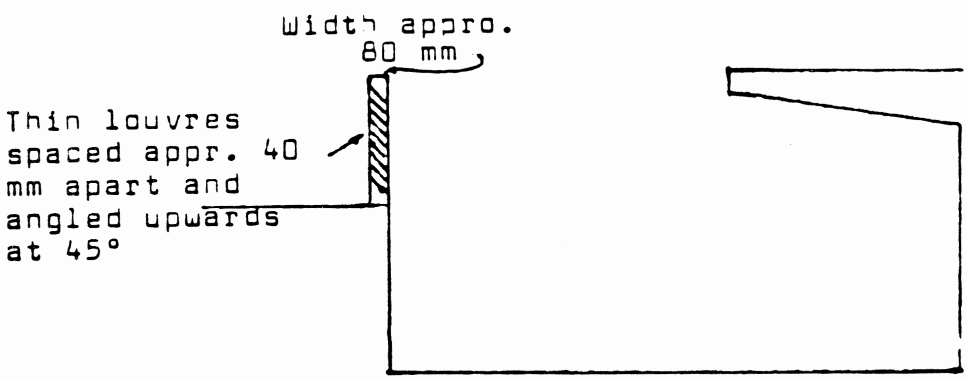
Please feel free to contact us at any time.

W. de V. Keet

W. DE V. KEET



Elevation



Cross Section

FIGURE 1. SCHEMATIC REPRESENTATION OF LOUVRES THROUGH ORCHESTRA PIT RAILING

APPENDIX 11

AKOESTIPLAN
AKOESTIESE RAADGEWERS — ACOUSTICAL CONSULTANTS

J. F. BURGER, Pr. Ing., B.Sc.(Ing.), Ph.D
W. de V. KEET, M.Sc., Ph.D

TEL. 47-7901

Rynlal 132,
The Hillside 320,
Lynnwood,
Pretoria.
0081

Ons verwysing: AH/79/45

19 September 1980.

Die Adjunk-Direkteur (Teaters),
KRUIK,
Posbus 6100,
KAAPSTAD.
8012

15 SEP - 0237

Geagte mnr. du Toit,

NICO MALAN SKOUBURG: LUGVERSORGINGSLAWAAI

Dit spyt my dat ek weens siekte en daaropvolgende groot drukte van werk nou eers by hierdie saak uitkom. Ek het onlangs die verslag met mnr. Pieter de Villiers bespreek. Hy was verbaas om te hoor van die hoë lugvolumes wat tans na die ouditorium gevoer word. Volgens hom is dit veels te hoog. Dit verklaar ook waarom die geraaspeile so hoog is - baie hoër as ooit. Toe die opera in gebruik geneem is, was die geraaspeil NR 25, nou is dit tot NC 38,5 (ongeveer NR 40), d.w.s. 15 dB hoër as oorspronklik! Geen wonder daar is klagtes oor die swak akoestiek en swak balans nie. Myns insiens is dit die grootste deel van die probleem.

Groete,

[signature]

ns. W. DE V. KEET

CAPAB KRUIK

CAPE PERFORMING ARTS BOARD
INCORPORATED ASSOCIATION NOT FOR GAIN
KAAPLANDSE RAAD VIR DIE UITVOERENDE KUNSTE
INGELYFDE VERENIGING SONDER WINSOOGMERK

2 May 1985

The Director of Works
Cape Provincial Administration
Private Bag X9078
CAPE TOWN
8000

ATTENTION: Mr MacKay

Dear Sir

AIR-CONDITIONING NOISE LEVELS : NICO MALAN THEATRE CENTRE

We got the firm APV Hall in on 23 April 1985 to take a reading on the noise levels in both the Theatre and Opera auditoria. I attach a copy of their report for your information.

I got our Chief Air-conditioning Technician, Mr Van Pareen, to comment on some of the conclusions in this report, and a copy of his comments is also attached.

I must add that the air volume to the Opera auditorium has not been increased. The fans have not been speeded up nor are the filters any cleaner (or dirtier) than they have been up till now. I should point out that Mr P de Villiers of C A du Toit & Partners is of the opinion that the air volume is far too high and should be reduced (I attach a copy of a letter from Dr Keet of Akoestiplan dated 19 September 1980 in which he refers to this).

Both Mr Van Pareen and myself are very reluctant to put this into practice, as the orchestra pit relies entirely on the auditorium for its conditioned air. As it is the situation in the pit is marginal (particularly in hot weather) and reducing the air volume to the auditorium could, in fact, make conditions in the pit completely unbearable. Further, (as APV Hall points out) reducing the air quantity will definitely have an effect on the temperature control.

I recommend that this aspect be thoroughly investigated before any action is taken.

I further recommend that the lagging and sound attenuators be replaced as soon as is practically possible.

Yours faithfully

PIETER DE SWARDT
TECHNICAL DIRECTOR

PdeS/ch

c.c. **Acting Chief Director**
Head of Maintenance
Chief Technician; Air-cond.

Provincial Secretary
Cape Provincial Administration
Private Bag 9077
CAPE TOWN
8000

Ref.: AC 4/20/9/2D

2 June 1988

Dear Sir

NICO MALAN THEATRE CENTRE : ACOUSTICS OF OPERA AUDITORIUM

I refer to your letter dated 25 April 1988 and the report by Messrs Akoestiplan that accompanied it.

Some comments on Dr Keet's recommendations:-

1) Recommendation 6.1.c. : Air-conditioning Noise Levels

   a) It should be possible to reduce the velocity of the air entering the auditoirum once the orchestra pit air-conditioning unit has been installed. The noise from the vents in the front of the auditorium is particularly noticeable, even to the unaided ear.

   b) It is generally agreed that the completely deteriorated internal lagging of the air-conditioning ducts is significantly contributory to the noise level. The replacement of this lagging should be continued as soon as possible.

2) Recommendation 6.2.a.

   The curtained orchestra pit rail to which Dr Keet refers was introduced some 10 years ago in an effort to improve the orchestra sound. Since the new seats and floor covering were introduced, we have reinstated the original orchestra pit rail, which has the acoustical properties to which Dr Keet refers. In fact, I believe this rail was designed by Dr Keet himself at the time the Nico Malan Theatre Centre was being built.

3) Recommendation 6.2.b. & 6.2.c.

We do vary the orchestra pit depth and the layout of the orchestra quite regularly depending on the demands of the work being presented.

Recommendation 6.2.c.

We will certainly experiment with sound absorbent curtains as suggested should we encounter problems with orchestra volume or balance in future.

In conclusion I would like to assure you that the remedial work done to the acoustics of both auditoria has been an unqualified success, a fact well supported by the lavish praise of the artists, public and press alike.

Yours faithfully

PIETER DE SWARDT
TECHNICAL DIRECTOR

PdeS/ch