structural decisions

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6 The Dome of Florence Cathedral by Brunelleschi is pure structure

7 Maillart's concrete arch designed for the Zürich Exhibition is parabolic and therefore an appropriate shape for a very thin shell

8 Nervi's great exhibition hall at Turin is based on a circular segment of approximately one quarter rise, so the pre-cast concrete 'voussoirs act in direct compression

9a Model arch built on the line of a circular segment rising a quarter of the span in close agreement with the near parabolic 'natural' thrust line

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10 A 'catenary' of six weights represents a 'natural' thrust line in reverse. The horizontal component H is represented by the pulley. The geometrically constructed line based on the same H is identical with the catenary

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13 The cantilevered roof of the Termini Station in Rome designed by Calini, Nassimo Castellazzi & Partners, reflects in its shape the distribution of the moments

foreword

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During recent years great changes can be observed in architectural education. These, no doubt, have been influenced by various industrial and technological developments, which have a far-reaching effect upon contemporary architecture.

The general trend, not only in this country, but also abroad, is to put a proper emphasis on architectural science.

Although intuition to visualise the shape, and ability to feel and express in a correct way the relationship between the environment and the structure is very important to the architect, and an enquiring mind essential in his search for the ideal solution, yet he must also have a clear idea of the behaviour of the structure he is designing.

The process of visualising a structure is certainly an art. There must, however, also be a close integration between the functional and structural requirements.

Nowadays, the design of any large structure is the work of a team; and normally the architect acts as co-ordinator between the various specialists advising him on diverse aspects of the design.

As a rule, it is the architect who decides on the shape of the structure and in the early stages of the design has to make structural decisions. He must, therefore, have a broad overall

knowledge of the various problems involved and must understand the fundamental principles of the behavour of his structure under the loading.

It is true that the detailed analysis will be carried out by a structural consultant, and, owing to the complexity of available architectural forms, such an analysis may become very involved, but the architect must himself arrive, at least at the beginning of his concept, at certain useful approximations.

Some engineers state that it is far easier for them (though it takes much more time) to carry out a long, 'precise' analysis than to produce an approximate, but reliable answer in a short time.

This shows, I think, how important it is to develop this particular sense of being able to judge the problem, to see through it, to simplify it and to note only the essential parts. There are not many people who know how to do this and there are very few books on structural analysis which teach how one is to get into this particular frame of mind whereby only the important aspects of the problem may be seen. There is no doubt that this book belongs in this category.

The Theory of Structures is so often taught, especially in architectural schools, as a very 'scientific', dry subject, presented in a boring way and made thoroughly uninteresting. The contrary, of course, is true. The study of the theory of structures can be most fascinating, even for an architect, as this book will show.

The structural principles influence the form and a logical solution (often the most economical one, too) is always based on a correct interpretation of these principles.

This volume is not a standard book on the mechanics of engineering structures. It was never meant to be.

It is not a book for structural engineers either, and some purists may even not agree with certain expressions or approaches used by the author, though I suspect strongly that many engineers will be caught with this book in their hands.

The main purpose of this book is to develop a feeling for structure and it will certainly help many an architect to take the correct 'structural decision'. And not only for simple

structures. The author succeeds in proving in a very convincing way that the basic fundamental principles are the same even for highly complex systems—and what is more important, he shows how to apply these principles in such cases.

Z. S. M.

preface

The subject called Theory of Structure holds a curious position in the education of the architect. To the engineer it is a full-time study, and while it appears traditionally on the curricula of schools of architecture all over the world, nobody seems to know quite how far architects could go without involving them to an extent indistinguishable from an engineering course. The very reason for the subject is often not clear, even to teachers, and, like Latin, it is considered in some vague way 'to do one good'.

The result is usually a hybrid course, stopping short of certain essentials which are considered too 'advanced', there is too much 'theory' and too little 'structure' so failing entirely to put across the only thing that matters, namely to awaken in the architect a structural sense, a 'stress consciousness'.

Thus the gulf between the architect and the engineer, which is something we have inherited from Victorian days and which in modern times, more than ever, should be narrowed, widens as each profession tends to specialise more and more in what it thinks is its particular sphere. Engineers, by their preoccupation with 'theory', have lost all sense of 'design' in the artistic sense which was once strong in the days of Telford and Brunel, while architects become more and more formalistic because 'anything can be made to stand up'.

In this country the situation is aggravated even more by the strict separation of the courses and because of the fact that mathematics at an advanced level is not a compulsory subject for architects. This puts Britain in a position unique among civilised nations.

While calculations do not produce good design, this fact nevertheless tends to deprive the architect of the ability to

grasp certain relationships which can be put across in a quick and concise way and can, in the mathematically-minded, conjure up structural images which entirely elude those to whom a formula is merely so many figures and symbols, to be 'swotted up' for an examination and promptly forgotten soon after.

This attitude is assisted by the shape and form of presentation of the subject in most textbooks, with their purely theoretical derivation of long formulae and anaemic diagrams.

This book is therefore an attempt to bridge the gap between the architect and the engineer by bringing out those aspects of theory which have a real influence on form and, thereby, the book is addressed also to the engineer who is apt to lose sight of this vital aspect of theory among a host of theorems.

The aim has been to make this an essentially *readable* book, remaining at the same time enough of a textbook in the accepted sense to be of real help to the student who tries to grasp the fundamentals of structural theory. Once these fundamentals are really understood, there are many specialised books on the calculation of steel, concrete or timber.

This book does not specialise in any material. On the contrary, it deals with the principles which are common to all materials and which chiefly affect form and lay-out. In this context, for instance, concepts like the moment of inertia, which are usually regarded as particularly abstract and incomprehensible, have been shown as some of the most vital aspects of theory and, it is hoped, have been brought to life.

All the sketches are purposely free and rarely to a precise scale. A ruler has only been used once for the graphic solution of a truss (111–112) and neither this nor any other example has been regarded as an end in itself, only as an illustration of structural occurrences.

In spite of this there is enough factual information to carry out simple calculations, often needed in practice for immediate dimensioning, and to carry out preliminaries for more complex structures which enable the architect to present the engineer with designs which are good and possible engineering.

Being *readable*, it is hoped that the book will appeal not only to the student at college, but also to that 'permanent student' the practising architect, that it will open up a fresh approach to design for the engineer, and perhaps be of help to the

general reader who is interested in problems of building and to whom an understanding of the basic principles of structure will reveal new perspectives. It is hoped that the book will assist in the appreciation of architecture in general and of the new forms and methods of which the best of today's architecture is made up and towards an understanding of the real meaning of the much-abused term of 'functional design', so often regarded as a synonym for dull utilitarianism, when it could be as exciting as a Gothic cathedral.

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chapter 1

introduction

The problem of the present age lies in its almost unlimited possibilities. These lead to doubts and uncertainties in all walks of life, but are nowhere more apparent than in architecture. Anything *can* be built and structural technique imposes hardly any limits.

Form need no longer be dictated by structure and concepts like 'structural truth' or 'honesty of expression' have already become meaningless, at least in the narrower sense. Many structural systems are available for the solution of identical building problems and identical structural systems have numerous applications. In view of this, a knowledge of structural theory seems to be of little help to the architect and too much of it, it has been argued, might even curtail his imagination. Design cannot be based on numbers. Furthermore, advanced structural form seems too complex to be understood by anyone other than the specialist, namely, the structural engineer. Yet structure is the raw material of building and the architect is the specialist in building. To use structure without understanding its implications is amateurish and results in meaningless formalism, quite apart from often avoidable expense.