MANUAL OF STRESSED SKIN DIAPHRAGM DESIGN

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Preface

After many years of virtual neglect, engineers are beginning to appreciate that there is enormous structural potential in the steel skin of a building. To neglect its influence on the performance of the structure as a whole is to waste a valuable asset. As steel becomes increasingly expensive, it becomes more important to realise this benefit both in traditional construction and by devising innovative structural forms designed to exploit it to the full.

The potential benefits of stressed skin diaphragm action first became apparent over 25 years ago when tests on actual buildings revealed stresses and deflections considerably smaller than those predicted by the usual design calculations. The nature of these buildings was such that the enhanced performance could only be attributed to the beneficial effect of the cladding. Since that time, continuous and extensive research has allowed the effect to be fully quantified and used in practical applications in many parts of the world.

The first book on the subject, *The Stressed Skin Design of Steel Buildings* by the second author, was published in 1973 and set out the principles of the design method together with design expressions and worked examples. The book is now out of print and has not been reprinted, since many of the design expressions in it have been superseded by more refined formulae obtained through recent research. However, the basic principles have remained unaltered.

The increasing utilisation of the diaphragm effect has been accompanied by the appearance of several National and International Codes of Practice and other Codes are known to be in the course of preparation. Of particular significance was the publication in 1977 by the European Convention for Constructional Steelwork of European Recommendations for the Stressed Skin Design of Steel Structures. The authors played an influential part in the preparation of these Recommendations which can be regarded as the definitive document of the state of the art at that time. The present book is strongly influenced by the European Recommendations and includes design procedures that are fully in accord with them. It also takes advantage of more recent research so that the coverage of the subject is complete and fully up-to-date.

The book has three parts. The first part is a design manual and gives all the information that a designer needs in order to be able to apply stressed skin design to most of the situations commonly found in practice. Chapters 1 to 6 describe the design procedure in detail and include all the relevant design expressions. Chapter 7 is a long chapter which gives a comprehensive set of worked examples. In chapter 8, a number of actual buildings using stressed skin construction are described. Part I is concluded by chapter 9 in which the design expressions are summarised and in which all the relevant design tables are collected together.

Part II of the book describes the derivation of the design expressions and summarises some of the more important pieces of research and testing which have led to the present state of the art. It also describes some of the more novel aspects of stressed skin action such as folded plate roofs in chapter 15 and light gauge steel shells in chapter 16. Stressed skin diaphragms can also be used to brace end gables and eaves, and to stabilise rafters. Consideration of these topics with some further worked examples is given in chapter 17.

The behaviour of fasteners is crucial to diaphragm action and this is discussed in chapter 13. The results of many fastener tests, from which design values for most practical situations can be deduced, are included in chapter 9.

An outline of diaphragm action in multi-storey buildings is given in chapter 18 and Part II is concluded in chapter 19 with a review of some practical considerations. Finally, Part III gives a complete list of all the relevant references known to the authors so that the reader can follow up any particular aspect by referring to the original work.

A particular advantage given by stressed skin calculations is that they describe the real behaviour of a structure much more accurately than calculations that consider frame action alone. This book is therefore written in the hope that it will not only lead to more efficient and enterprising structural design but also that it will help engineers and architects to achieve a fuller understanding of how real buildings behave.

The authors would like to express their gratitude to the many individuals who have helped to make the publication of this book possible. Various Research Fellows and Research Students have worked on the subject and the authors gladly acknowledge their contribution to the state of the knowledge. Particular thanks are due to Mrs J. Blood for typing the manuscript, Mr R. Bennett for preparing the diagrams and Mr C. Tivey for many of the photographs.

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PART ONE

DESIGN METHOD AND EXAMPLES

CHAPTER ONE

Introduction

1.1 Historical background

Interest in stressed skin design dates back to the early 1950s when tests on steel portal framed structures revealed measured stresses and deflections that were considerably smaller than those predicted by the usual design calculations. The structures concerned were of the factory or warehouse type without internal floors or partitions so that the only explanation for the reduced stresses was that the profiled steel sheet cladding was helping the frames to carry the load. This reasoning prompted the second author to commence research into the stiffening effect of light steel cladding and this research has continued first at the University of Manchester and later at the University of Salford up to the present time.

A landmark in the development of the principles of stressed skin design was the publication of the first book on the subject[1.57]* and this remained the only comprehensive work on the subject until the publication by the European Convention for Constructional Steelwork of the *European Recommendations for the Stressed Skin Design of Steel Structures.*[1.99] These recommendations are based on the work of the authors and are now widely recognised as the definitive reference on the subject. The design procedures and expressions which are described in the present book are fully in accordance with the European recommendations. An important feature of the authors' work has been the development of simple methods of calculation and design aids and these will be fully described in the following chapters.

1.2 The present situation

At the time of writing, stressed skin design is not incorporated in the provisions of the relevant British Standard specification for 'The use of structural steel in building'

* A comprehensive bibliography containing over 200 references in chronological order is given at the end of the book.

(*B.S. 449*) and this has tended to restrict its application to certain types of building. However, the draft of a new standard[1.113] containing clauses permitting stressed skin design was released for public comment in 1978. The present position is that the new British Standard on 'The structural use of steelwork in building' will be *B.S. 5950* and that stressed skin design will constitute Part 9.

To date, the majority of stressed skin structures built in Britain have been system built and indeed many of the major systems used for low-rise steel framed construction (e.g. CLASP, SEAC, SCOLA) rely on stressed skin action for their stability. In the early 1970s, at the height of the school building programme, stressed skin structures to the value of many millions of pounds per annum were built in the CLASP and SEAC systems alone. Figs. 1.1 and 1.2 show typical stressed skin structures of this type.

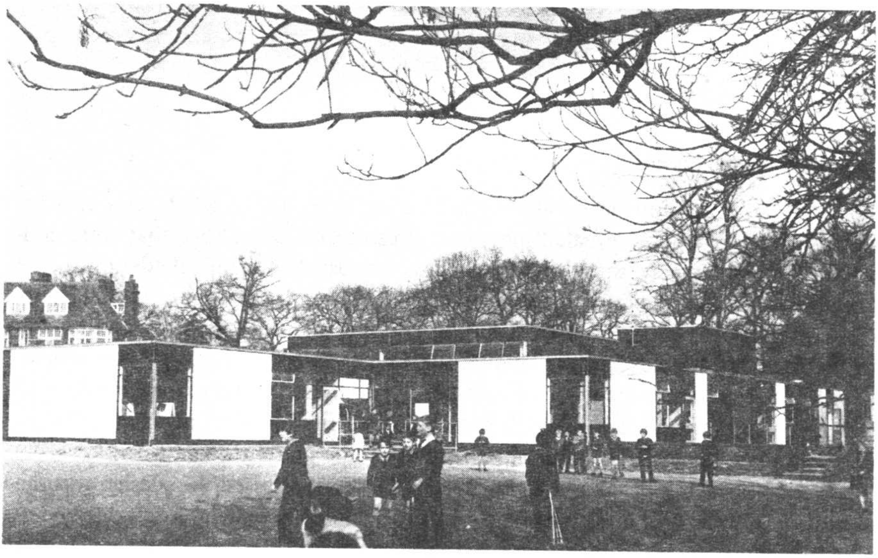

Fig. 1.1 SEAC school building.

Another type of structure for which stressed skin design has been used has been the major prestige structure which has justified the trouble of obtaining a Building Regulations waiver to permit this approach to design. A notable example of this type is the New Covent Garden fruit and vegetable market shown in fig. 1.3. The acceptance of stressed skin design for this project by the Greater London Council represented an important step forward in the practical utilisation of the stressed skin principle.

Relevant national Standards either exist or are in draft form in Australia, Canada, Czechoslovakia, Germany and Sweden. In the U.S.A., stressed skin design based on testing has been permitted for many years[1.15] together with associated empirical and semi-empirical methods of design[1.41, 1.48] and numerous structures

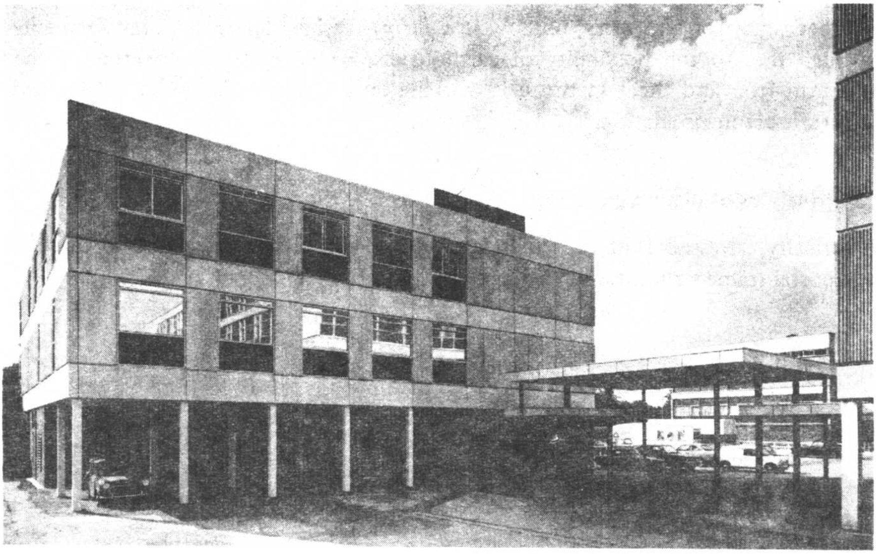

Fig. 1.2 CLASP computer building at Nottingham.

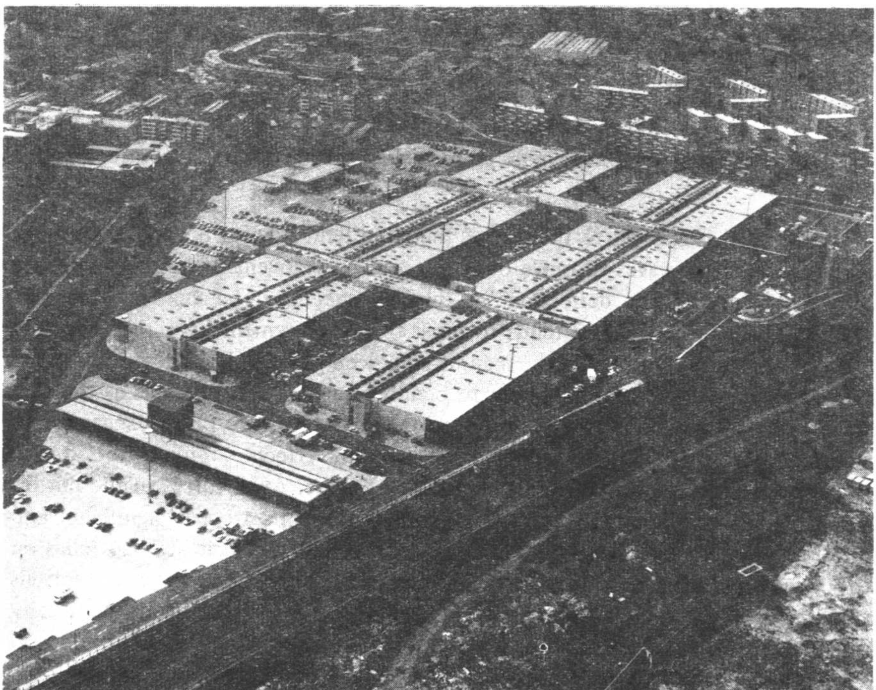

Fig. 1.3 New Covent Garden fruit and vegetable market. (*Photograph by Handford Photography*)

have been built on this basis, notably in California where lateral load requirements are high due to the possibility of earthquakes. At present, a committee of the American Iron and Steel Institute is working on a code for design by calculation and drafts are in circulation.[1.114]

1.3 Principles of diaphragm action

Historically, stressed skin or diaphragm action was first appreciated in pitched roof portal frame structures of the type shown in fig. 1.4.

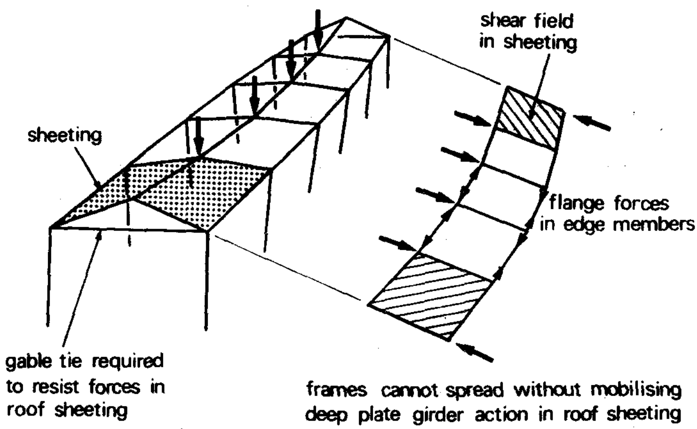

Fig. 1.4 Stressed skin action in a pitched roof portal frame structure carrying vertical load.

As vertical load is applied to the frames there is a tendency for the apexes to move downwards and the eaves to move outwards and this movement cannot take place without causing in-plane deflections of the roof sheeting. The sheeting has considerable in-plane stiffness and tends to resist this displacement by acting, together with the supporting purlins, in the manner of a deep plate girder. The purlins act as flanges carrying the axial forces due to bending and the sheeting acts as the web carrying the shear. Because of the proportions of typical roof planes, shear forces and shear deformations predominate over bending effects so that stressed skin design is primarily concerned with the effect of shear. Axial forces in the purlins caused by bending and their corresponding displacements are also significant and must be considered. Evidently the stressed skin action shown in fig. 1.4 relies on restraint at the gables, usually in the form of an eaves tie, to carry the end reactions from the deep plate girder action described above. As such a restraint is usually present for reasons other than that of promoting stressed skin action, stressed skin action is almost always present, whether or not the designer is aware of it.

Although initial interest in stressed skin design arose from a consideration of the behaviour of pitched roof portal frames, more recently attention has been concentrated on flat-roofed structures of the type shown in fig. 1.5. Here side loads at

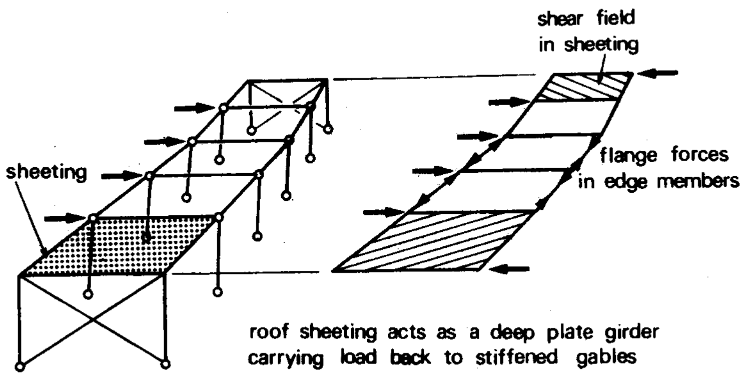

Fig. 1.5 Stressed skin action in a flat-roofed structure with non-rigid frames.

eaves level are applied directly in the plane of the sheeting so that such loads are very efficiently resisted by the stressed skin action of the sheeting which acts as a deep plate girder in the manner described above. This form of stressed skin action is so effective that it is often possible to dispense with both rigid-jointed frame action and wind bracing in this type of structure and to rely entirely on the sheeting for stability. As before, stressed skin action is dependent on there being provision at the gables to carry the end reactions from the roof diaphragm. This may take the form of diagonal bracing as shown in fig. 1.5, or alternatively the sheeted gable may itself act as a diaphragm carrying the forces in the roof to the foundations. It is clear that in fig. 1.5 stressed skin action is of no help in carrying vertical load and this leads to an important general principle, namely that stressed skin action only helps to carry loads that cause displacement of the joints of the structure in the plane of the sheeting. It is of no help in resisting the 'no sway' distribution of load. It follows that for the pitched roof frame of fig. 1.4 stressed skin action is also of considerable benefit in resisting side load on the structure but that, for vertical load, the influence of stressed skin action depends on the angle of pitch of the roof and as this reduces so do the benefits of stressed skin action.

1.4 Types of building suitable for stressed skin design

It is convenient to divide stressed skin structures into two distinct types, as follows:

1.4.1 Type 1. Diaphragms acting alone

This is typically a low-rise, flat-roofed structure in which the connections between the beams and the columns are nominally pinned and the stability of the structure depends entirely on diaphragm action in the roof and intermediate floors (if any). In Britain this has been by far the most frequent use of stressed skin design and is the basis of a number of building systems. As a result, not only is wind bracing omitted in the plane of the roof but it is claimed that even greater savings are possible as a consequence of the simplification of the system and the reduction in the number of components and joint details. The New Covent Garden fruit and vegetable market (fig. 1.3) is also an example of this type.