FIRE DESIGN OF STEEL STRUCTURES

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Eurocode 1: Actions on structures
Part 1-2 – General actions – Actions on structures exposed to fire
Eurocode 3: Design of steel structures
Part 1-2 – General rules – Structural fire design

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Design of Steel Structures

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FOREWORD

Designing for fire is an important and essential requirement in the design process of buildings and civil engineering structures. Within Europe the fire resistance requirements for buildings are specified in the national Building Regulations. All buildings must meet certain functional requirements and these are usually linked to the purpose and height of the building. For the purpose of this publication, the most important requirement is for the building to retain its stability for a reasonable period. This requirement has traditionally been linked to the required time of survival in the standard fire test. The most common method of designing a steel structure for the fire condition is to design the building for the ambient temperature loading condition and then to cover the steel members with proprietary fire protection materials to ensure that a specific temperature is not exceeded. Although this remains the simplest approach for the majority of regular steel framed buildings, one of the drawbacks with this approach is that it is often incorrectly assumed that there is a one to one correspondence between the survival time in the standard fire test and the survival time in a real fire. This is not the case and real fire can be more or less severe than the standard fire test depending on the characteristics of the fire enclosure.

The fire parts of the Eurocodes set out a new way of approaching structural fire design. To those more familiar with the very simple prescriptive approach to the design of structures for fire, the new philosophy may appear unduly complex. However, the fire design methodology in the Eurocodes affords the designer much greater flexibility in his approach to the subject. The options available range from a simple consideration of isolated member behaviour subject to a standard fire to a consideration of the physical parameters influencing fire development coupled with an analysis of the entire building.

The Eurocode process can be simplified in to three components consisting of the characterisation of the fire model, a consideration of the temperature distribution within the structure and an assessment of the structural response

to the fire. Information on thermal actions for temperature analysis is given in EN 1991-1-2 and the method used to calculate the temperature rise of structural steelwork (either protected or unprotected) is found in EN 1993-1-2. The design procedures to establish structural resistance are set out in EN 1993 but the actions (or loads) to be used for the assessment are taken from the relevant parts of EN 1991.

This publication follows this sequence of steps. Chapter 2 explains how to calculate the mechanical actions (loads) in the fire situation based on the information given in EN 1990 and EN 1991. Chapter 3 presents the models that may be used to represent the thermal actions. Chapter 4 describes the procedures that may be used to calculate the temperature of the steelwork from the temperature of the compartment and Chapter 5 shows how the information given in EN 1993-1-2 may be used to determine the load bearing capacity of the steel structures. The methods used to evaluate the fire resistance of bolted and welded connections are described in Chapter 7. In all of these chapters the information given in the Eurocodes is presented in a practical and usable manner. Each chapter also contains a set of easy to follow worked examples.

Chapter 8 describes a computer program called ‘Elefir-EN’ which is based on the simple calculation model given in the Eurocode and allows designers to quickly and accurately calculate the performance of steel components in the fire situation. Chapter 9 looks at the issues that a designer may be faced with when assessing the fire resistance of a complete building. This is done via a case study and addresses most of the concepts presented in the earlier chapters. Finally the annexes give basic information on the thermal and mechanical properties for both carbon steel and stainless steel.

The concepts and fire engineering procedures given in the Eurocodes may seem complex to those more familiar with the prescriptive approach. This publication sets out the design process in a logical manner giving practical and helpful advice and easy to follow worked examples that will allow designers to exploit the benefits of this new approach to fire design.

David Moore
BCSA Director of Engineering

PREFACE

When a fire breaks out in a building, except in very few cases, the structure has to perform in a satisfactory manner in order to meet various objectives such as, e.g., to limit the extension of the fire, to ensure evacuation of the occupant or to allow safe operations by the fire brigade. Steel structures are no exception to this requirement.

Eurocode 3 proposes design methods that allow verifying whether the stability and resistance of a steel structure is ensured. A specific Part 1-2 of Eurocode 3 is dedicated to the calculation of structures subjected to fire. Indeed, the fact that the stress-strain relationship becomes highly non-linear at elevated temperatures, plus the fact that heating leads to thermal expansion with possible restraint forces, make the rules derived for ambient temperature inaccurate in the fire situation.

After a long evolution and maturation, the Eurocodes have received the status of European standards. The fire part of Eurocode 3 is EN 1993-1-2. This makes the application of these rules mandatory in member states of the European Community. In many other parts of the world, these standards are considered as valuable pieces of information and their application may be rendered mandatory, either by law or by contractual imposition.

Nevertheless, standards are not written with pedagogic objectives. Yet, for a designer who has not been involved in the research projects that are at the base of the document, some questions may arise when the rules have to be applied to practical cases.

The objective of this book is to explain the rules, to give some information about the fundamental physics that is at the base of these rules and to show by examples how they have to be applied in practice. It is expected that a designer who reads this book will reduce the probability of doing a non appropriate application of the rules and, on the contrary, will be in a better position to make a design in a situation that has not been explicitly foreseen in the code.

A design in the fire situation is based on load combinations that are different from those considered at room temperatures. Actions on structures from fire

exposure are classified as accidental actions and the load combinations for the fire situation are given in the Eurocode, EN 1990. The thermal environment created by the fire must also be defined in order to calculate the temperature elevation in the steel sections and different models are given in part 1.2 of Eurocode 1 for representing the fire. In order to encompass in one single document all aspects that are relevant to the fire design of steel structures, this book deals with the fire part of Eurocode 1 as well as that of Eurocode 3.

The requirements, i.e., for example, the duration of stability or resistance that has to be ensured to the structure, is not treated in the Eurocodes. This aspect is indeed very often imposed by the legal environment, especially when using a prescriptive approach, or has to be treated separately by, for example, a risk analysis based on evacuation time. In line with the Eurocodes, this book does not deal with the requirement.

A computer program, Elefir-EN, which has been developed for the fire design of structural members in accordance with the simple calculation models given in the Eurocodes, is supplied with this book. The software is an essential tool for structural engineers in the design office, enabling quick and accurate calculations to be produced, reducing design time and the probability of errors in the application of the equations. It can also be used by academics and students.

The program has been carefully checked for reliability and do not contain any known errors, but the authors and the publisher assume no responsibility for any damage resulting from the use of this program. No warranty of any type is given or implied concerning the correctness or accuracy of any results obtained from the program. It is the responsibility of the program user to independently verify any analysis results. Please contact the authors if any errors are discovered. The program is licensed to the purchasers of this book who are strongly encouraged to register in its web site so that any updated version can be delivered.

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