

CONTENTS

List of Figures	iv
List of Tables	x
Notation	xi
Acknowledgment	xvi
1. Introduction	1
1.1. State-of-the-art.....	1
1.1.1. Performance-based fire engineering	1
1.1.2. Advancements in the solving of structural fire engineering problems	9
1.2. Research objectives and the concept of the thesis	11
2. Theoretical background	17
2.1. Fluid dynamics in fire engineering	17
2.1.1. Fundamental laws of fluid dynamics and heat transfer	18
2.1.2. Turbulence modelling.....	25
2.1.3. Combustion.....	29
2.1.4. Soot production.....	31
2.1.5. Radiation	32
2.2. Nonlinear solid mechanics in performance-based structural fire design ..	37
2.2.1. Formulation of a linear elastic problem.....	37
2.2.2. Finite Element Method in linear elastic problems	39
2.2.3. Large strain-displacement formulation.....	41
2.2.4. Material nonlinearity in structural fire engineering problems	45
2.2.5. Stiffness of a structural element in fire.....	54
2.2.6. Solution of a nonlinear problem	56
2.3. Physical bases for heat exchange between the fire environment and the structure.....	65
2.3.1. Convective heat flux.....	66
2.3.2. Radiative heat flux.....	68
2.3.3. Adiabatic surface temperature	69
2.3.4. Heat conduction.....	79
3. Coupling between the fire and the mechanical models	81

3.1. Concept of CFD-FEM coupling81

3.2. Incompatibility between CFD and FEM models
for steel framed structures81

3.3. Development of a heat transfer model.....84

3.3.1. Virtual surfaces.....84

3.3.2. Shadow effect86

3.3.3. Heat transfer model formulation.....87

3.4. Implementation.....96

3.4.1. Approximate calculation of view factors.....98

3.4.2. Verification of the view factors calculation method.....102

3.4.3. Finite difference method approximation of a conduction problem108

3.5. Verification and Validation112

3.5.1. Furnace tests with uniform thermal exposure of a cross-section113

3.5.2. Furnace tests with nonuniform thermal exposure of a cross-section.....116

3.5.3. Compartment fire tests.....123

3.5.4. Localised fire tests127

3.5.5. Summary140

3.6. CFD-FEM coupling procedure141

3.6.1. Setting CFD output.....142

3.6.2. Heat transfer calculations142

4. Mechanically based method for determining fire scenarios145

4.1. Complexity and robustness of frame structures.....145

4.2. The idea of the method147

4.3. Theoretical bases150

4.4. Complexity measures151

4.5. Method implementation.....153

4.6. Verification.....155

5. Exemplary analysis of a structure subjected to fire171

5.1. General description of the structure.....171

5.2. Actions.....171

5.2.1. Fire actions172

5.2.2. Permanent loads..... 175

5.2.3. Imposed loads..... 176

5.2.4. Snow load 177

5.2.5. Wind load 177

5.2.6. Combinations of actions 178

5.3. Preliminary analyses..... 183

5.3.1. Design according to Eurocode simple calculation model..... 183

5.3.2. Response to uniform ISO 834 fire exposure..... 184

5.4. Numerical models..... 187

5.4.1. CFD fire model..... 187

5.4.2. FEM mechanical model..... 191

5.5. Fire scenario determination 193

5.6. CFD-FEM coupling..... 197

5.7. Results 199

5.7.1. Temperature distribution in a fire compartment..... 200

5.7.2. Fire-structure heat transfer results 203

5.7.3. Effect of combinations of actions on the mechanical response
of the structure in fire 215

5.7.4. Local response of the structure in fire 216

5.7.5. Global response of the structure in fire..... 242

5.7.6. Summary 256

6. Concluding remarks..... 259

References..... 265

Appendices..... 278

Summary 279