Contents

1 Introduction **1**

1.1 Background 1

1.2 Fire scenarios 2

(1.2.1 Real fires – 1.2.2 Nominal fire curves – 1.2.3 "Natural" fires - Parametric curves in buildings – 1.2.4 Multi-zone & CFD models)

2 Assessment of thermal/structural response to fire **6**

2.1 Background 6

2.2 Fire resistance 6

(2.2.1 Requirements – 2.2.2 The load bearing function – 2.2.3 The separating function – 2.2.4 Requirements)

2.3 Scope of assessment 9

2.4 Levels of structural assessment 9

(2.4.1 Single member assessment – 2.4.2 Substructure assessment – 2.4.3 Global structural assessment)

2.5 Methods of assessment of fire resistance 11

(2.5.1 Fire testing – 2.5.2 Tabulated data – 2.5.3 Calculation based methods)

2.6 Failure modes in fire 23

(2.6.1 Bending failure – 2.6.2 Buckling/compression failure – 2.6.3 Anchorage/ bond failure – 2.6.4 Shear or torsional failure – 2.6.5 Spalling failure)

3 Fire and concrete material **26**

3.1 Complex behaviour has lead to versatility 26

3.2 Causes for misunderstanding 26

3.3 Key influences 26

(3.3.1 Concrete type – 3.3.2 Test regime)

3.4 Microstructure 29

(3.4.1 Importance of microstructure – 3.4.2 "Concrete type" and not "concrete" – 3.4.3 Cement Paste – 3.4.4 Aggregate – 3.4.5 Bond region – 3.4.6 Interaction between the aggregate and cement paste)

4 Thermal properties **51**

4.1 Thermal diffusivity 51

4.2 Thermal conductivity 52

4.3 Density 54

4.4 Specific heat 55

5 Strains during heating **58**

5.1 Thermal strains 58

5.2 Load Induced Thermal Strain (LITS) 59

5.3 Strain components 64

(5.3.1 Unloaded Unsealed Concrete – 5.3.2 Loaded Unsealed Concrete)

5.4 Isolation of shrinkage and creep components 66

(5.4.1 Drying shrinkage – 5.4.2 LITS Component)

6 Spalling of concrete **67**

6.1 Definition, significance and types of spalling 67

6.2 Explosive spalling 67

(6.2.1 Factors influencing explosive spalling – 6.2.2 Mechanisms of explosive spalling)

6.3 Methods of analysis used 71

(6.3.1 Large scale tests – 6.3.2 Use of nomograms – 6.3.3 Theoretical models – 6.3.4 Numerical models – 6.3.5 Expert Assessment)

6.4 Passive fire protection against spalling 74

6.5 Simple tunnel example of spalling assessment 75

(6.5.1 Influence of concrete parameters – 6.5.2 Explosive spalling assessment)

7 Mechanical properties **77**

7.1 Stress-strain relation and mix design 77

7.2 Stress-strain relation 77

(7.2.1 Maximum temperature level – 7.2.2 Load level during heating – 7.2.3 Point of testing – 7.2.4 Moisture condition – 7.2.5 Loading technique)

7.3 Modulus of elasticity 81

(7.3.1 Modulus of elasticity and strength – 7.3.2 Temperature effect – 7.3.3 Effect of pre-loading)

7.4 Compressive strength 84

(7.4.1 Influence of LITS – 7.4.2 Influence of loading during heating – 7.4.3 Influence of temperature)

7.5 Mix design against strength loss and spalling 88

(7.5.1 Aggregate – 7.5.2 Cement blend)

8 References **92**