

Contents

Foreword	i
1. Introduction	1
1.1 Scope of the document	1
1.2 Fibre Reinforced sprayed concrete in tunnels and underground spaces	2
2. Functional requirements	3
2.1 Spaceproofing and tolerances	3
2.2 Design Service Life	3
2.3 Watertightness of the Completed Tunnel	3
2.4 Surface Finish of the Inner Lining	4
3. Material performances	5
4. Mechanical characterisation	9
4.1 Early Age	9
4.2 Long term	10
4.2.1 Strength	10
4.2.2 Ductility – strain capacity	10
5. Loading conditions	12
6. Structural design	14
6.1 Design analysis	14
6.1.1 Empirical approach	14
6.1.2 Analytical approach	15
6.1.3 Numerical analysis	15
7. Fire resistance	22
8. Construction & application good practice (joints, equipment, safety, competences)	25
8.1 The Sprayed FRC	25
8.1.1 Batching	25
8.1.2 Storage	25
8.2 Key site personnel	26
8.2.1 The Nozzleman (NM)	26
8.2.2 The Pump Operator (PO)	26

8.3 The Equipment	26
8.3.1 The Robot sprayer	26
8.3.2 The Pump	26
8.3.3 The Compressor	27
8.4 Quality	27
8.4.1 Profile Control	27
8.4.2 Rebound	28
8.4.3 Cleanliness	28
8.4.4 Joint Preparation	29
8.5 Safety	30
8.5.1 Exclusion Zones	30
8.5.2 Ventilation	32
8.5.3 Pressure Systems and Blowing Out	32
9. Durability	33
9.1 Durability of FRC	33
9.1.1 Steel fibres	33
9.1.2 Non-metallic fibres	33
9.2 Crack widths limits for SFRC	33
9.3 Use of sacrificial layer in SFRC lining	34
10. Quality control	35
11. Case studies	40
11.1 Model geometry	40
11.2 Material parameters	41
11.3 Model discretisation	44
11.4 Analysis settings	44
11.5 Results	46
11.6 Discussion	48
11.7 Conclusions	48
APPENDIX 1: Definition of $M-N$ envelopes at ULS	49
APPENDIX 2: Definition of $M-N$ envelopes at SLS	52
APPENDIX 3: Example of level of investigations applied to case study	56
References	59