

# Contents

<b>1</b>	<b>INTRODUCTION .....</b>	<b>7</b>
1.1	Principle of prestressed concrete.....	7
1.2	History of prestressed concrete.....	8
1.3	Structural behaviour of prestressed concrete.....	9
<b>2</b>	<b>MATERIAL PROPERTIES .....</b>	<b>11</b>
2.1	Concrete.....	11
2.1.1	Composition of concrete mix .....	11
2.1.2	Stress-strain relationship.....	12
2.1.3	Tri-axial stress conditions .....	14
2.1.4	Fatigue properties of concrete .....	15
2.1.5	Modulus of elasticity.....	16
2.1.6	Ageing of concrete .....	17
2.1.7	Creep and shrinkage of concrete .....	18
2.1.8	Components of concrete strain.....	20
2.1.9	Calculation of strain in concrete under constant stress .....	21
2.1.10	Calculation of strain in concrete under variable stress .....	21
2.1.11	Selected rheological models.....	23
2.1.12	Example of calculation of concrete strain under variable stress.....	27
2.1.13	Example of calculation of creep of axially loaded member .....	28
2.2	Reinforcement .....	33
2.3	Prestressing reinforcement .....	34
2.3.1	Production and basic characteristics of prestressing reinforcement.....	34
2.3.2	Relaxation of prestressing reinforcement.....	36
2.3.3	Fatigue properties of prestressing reinforcement .....	39
2.3.4	Bond between prestressing reinforcement and concrete .....	40
2.4	Grout.....	40
<b>3</b>	<b>TECHNOLOGY OF PRESTRESSED CONCRETE .....</b>	<b>42</b>
3.1	Basic terminology.....	42
3.2	Pre-tensioned prestressed concrete .....	43
3.3	Post-tensioned prestressed concrete .....	47
3.3.1	Bonded multi-strand prestressing system.....	47
3.3.2	Unbonded single-strand prestressing systems .....	54
3.3.3	Prestressing systems using prestressing bars .....	56
3.3.4	Prestressing systems with external unbonded reinforcement .....	57
3.3.5	Wire wound concrete structures and circumferential prestressing .....	58
<b>4</b>	<b>LOSSES OF PRESTRESSING .....</b>	<b>60</b>
4.1	Loss of prestressing due to friction.....	61
4.2	Anchorage set loss.....	66
4.2.1	Anchorage set loss with friction not taken into account .....	66
4.2.2	Anchorage set loss when tendon is stressed from one end only.....	66
4.2.3	Anchorage set loss when tendon is stressed from both ends.....	69
4.3	Loss of prestressing due to immediate elastic strain in concrete .....	72
4.3.1	Loss of prestressing due to immediate elastic strain in concrete at stressing .....	73
4.3.2	Loss of prestressing due to sequential stressing .....	75
4.3.3	Loss of prestressing due to elastic strain in concrete resulting from external load .....	78
4.4	Loss of prestressing due to relaxation of prestressing reinforcement .....	78
4.5	Loss of prestressing due to deformation of end abutments of stressing bed.....	80
4.6	Loss due to differences in the temperature of the prestressing reinforcement and stressing bed ..	81
4.7	Draw-in loss of prestressing .....	82
4.8	Loss of prestressing due to creep and shrinkage of concrete .....	82
<b>5</b>	<b>EFFECTS OF PRESTRESSING ON CONCRETE ELEMENTS AND STRUCTURES, DESIGN OF PRESTRESSING .....</b>	<b>86</b>
5.1	Action stages of prestressed structure.....	86
5.2	Equivalent load method.....	89
5.2.1	Force action of a tendon on the concrete.....	89

5.2.2	Equivalent load for a parabolic tendon profile .....	91
5.2.3	Beams with variable cross-section .....	92
<b>5.3</b>	<b>Statically indeterminate effects of prestressing.....</b>	<b>93</b>
5.4	Concordant tendon .....	95
5.5	Linear transformation of a tendon .....	97
5.6	Statically indeterminate effects of prestressing on prestressed slabs .....	98
5.7	Design of prestressing by using the load balancing method.....	99
<b>6</b>	<b>LIMITATION OF STRESSES DUE TO SERVICE LOAD, LIMITING ZONE FOR THE LOCATION OF THE TENDON .....</b>	<b>103</b>
6.1	Limitation of normal stresses due to service load effects .....	103
6.2	Crack resistance and brittle failure.....	105
6.3	Limiting zone for the location of the tendon.....	107
6.4	Limiting zone for the pressure line.....	110
<b>7</b>	<b>STRUCTURAL ANALYSIS OF SEGMENTALLY CONSTRUCTED PRESTRESSED STRUCTURES.....</b>	<b>112</b>
7.1	Properties of modern segmentally constructed structures .....	112
7.2	Non-homogeneity of structures.....	112
7.3	Closed form solution of rheological effects on the structure .....	114
7.4	Time discretisation method.....	123
7.5	Example of calculation using time discretisation method .....	126
7.6	Simplified methods for the analysis of rheological effects on structures .....	133
7.7	Time-dependent analysis of prestressed concrete structures .....	135
7.7.1	Structural analysis, static model.....	135
7.7.2	Modelling of changes in the configuration of structures.....	137
7.7.3	Analysis of rheological effects on the structure .....	137
7.7.4	Calculation procedure .....	138
<b>8</b>	<b>ULTIMATE RESISTANCE OF ELEMENTS SUBJECTED TO AXIAL FORCE AND BENDING MOMENT.....</b>	<b>140</b>
8.1	Prestressed member subjected to tensile axial load .....	140
8.2	Ultimate resistance of cross-section subjected to flexure using the state of decompression.....	144
8.2.1	Determination of the decompression stress in the cross-section subjected to flexure.....	144
8.2.2	Determination of ultimate resistance of the cross-section subjected to flexure .....	146
8.2.3	Universality of solution.....	151
8.3	Ultimate resistance of cross-sections subjected to flexure with regard to the initial stress-state of the cross-section .....	153
8.4	Secondary effect of prestressing in the ultimate limit state of the structure .....	155
<b>9</b>	<b>ELEMENTS SUBJECTED TO SHEAR AND TORSION .....</b>	<b>157</b>
9.1	Nature of the action of prestressed elements .....	157
9.2	Design based on condition of elastic behaviour .....	158
9.3	Ultimate resistance of prestressed concrete members .....	163
9.3.1	Principles of variable-angle truss model .....	163
9.3.2	Some remarks to variable-angle truss model .....	168
9.4	Shear at the interface between composite parts of prestressed concrete section.....	171
9.4.1	Shear at the interface according to EN 1992-1-1 .....	171
9.4.2	Shear at the interface calculated from difference of normal forces.....	173
9.4.3	Composite concrete bridge analysis.....	175
9.5	Interaction of internal forces .....	176
<b>10</b>	<b>ANALYSIS OF THE ANCHORAGE ZONE .....</b>	<b>180</b>
10.1	Anchoring by means of anchors .....	180
10.1.1	Stress distribution in anchorage zones .....	180
10.1.2	Calculation model and check of zones under anchors .....	182
10.1.3	Reinforcement of the anchorage zone .....	185
10.2	Anchoring through the bond between the reinforcement and concrete.....	187
10.2.1	Stress distribution in pre-tensioned anchorage zones .....	187
10.2.2	Check of anchoring in pre-tensioned concrete .....	188
10.2.3	Direct support of pre-tensioned beam .....	190
10.2.4	Check of splitting forces in anchorage zone of pre-tensioned beam .....	191
<b>11</b>	<b>SERVICEABILITY LIMIT STATES .....</b>	<b>192</b>
11.1	Limitation of stress .....	192

<b>11.2</b>	<b>Crack control .....</b>	<b>192</b>
11.2.1	Tensile stresses in the concrete after cracking.....	193
11.2.2	Calculation of crack width .....	196
<b>11.3</b>	<b>Deflection control.....</b>	<b>197</b>
<b>11.4</b>	<b>Study of serviceability limit states of pre-tensioned girder .....</b>	<b>199</b>
<b>12</b>	<b>ADDENDUM A – PRINCIPLES OF PLASTIC ANALYSIS USING STRUT AND TIE MODEL.....</b>	<b>202</b>
12.1	<b>Extremum principles explained in laymen's terms.....</b>	<b>202</b>
12.2	<b>Analysis of concrete structures using the strut and tie model.....</b>	<b>203</b>
12.2.1	Subdivision of the structure into B- and D-regions .....	204
12.2.2	Definition of the geometry of the strut and tie model .....	204
12.2.3	Calculation of internal forces .....	205
12.2.4	Sizing of ties and struts .....	205
12.2.5	Model optimisation .....	207
12.2.6	Check that detailing provisions are followed .....	207
<b>13</b>	<b>SYMBOLS .....</b>	<b>208</b>
13.1	Latin letters .....	208
13.2	Greek letters .....	210
<b>14</b>	<b>LITERATURE .....</b>	<b>213</b>
14.1	Monographs and textbooks.....	213
14.2	Technical papers and reports .....	214
14.3	Standards and regulations .....	214
14.4	Computer programs .....	215