

Contents

- I. **PRESTRESSED CONCRETE ROAD BRIDGE 13**
 - 1. INTRODUCTION 14
 - 2. STRUCTURE 15
 - 2.1 Schema of the structure 15
 - 2.2 Process of construction 16
 - 2.3 Properties of the full cross section 17
 - 2.4 Effective width of flanges 18
 - 2.5 Properties of the cross section with effective width of flanges ... 19
 - 3. MATERIALS 20
 - 3.1 Concrete 20
 - 3.1.1 Basic properties 20
 - 3.1.2 Volume changes of concrete 22
 - 3.1.2.1 *Shrinkage of concrete* 22
 - 3.1.2.2 *Creep of concrete* 27
 - 3.2 Prestressing steel 32
 - 3.3 Reinforcing steel 34
 - 4. ACTIONS 35
 - 4.1 Permanent loads 35
 - 4.1.1 Own weight of superstructure 35
 - 4.1.2 Own weight of bridge equipment 35
 - 4.1.3 Uneven settlements of supports 36
 - 4.2 Variable loads 36
 - 4.2.1 Traffic loads 36
 - 4.2.1.1 *Notional lanes* 36
 - 4.2.1.2 *Load model 1* 37
 - 4.2.1.3 *Load model 2* 38
 - 4.2.1.4 *Load model 3* 39
 - 4.2.1.5 *Load model 4* 40
 - 4.2.1.6 *Load model 3 for fatigue* 40
 - 4.2.1.7 *Actions on footways* 41
 - 4.2.1.8 *Groups of traffic loads* 41

4.2.2	Thermal actions	41
4.2.2.1	<i>Distribution of temperature over the cross section – - increase of temperature</i>	<i>43</i>
4.2.2.2	<i>Distribution of temperature over the cross section – - decrease of temperature</i>	<i>44</i>
4.2.3	Construction load	44
4.3	Combinations of actions	45
4.3.1	Ultimate limit states	45
4.3.1.1	<i>Introduction</i>	<i>45</i>
4.3.1.2	<i>Combinations</i>	<i>45</i>
4.3.2	Serviceability limit states	46
4.3.2.1	<i>Introduction</i>	<i>46</i>
4.3.2.2	<i>Combinations</i>	<i>46</i>
4.3.3	Partial and combination coefficients	47
5.	DETERMINATION OF INTERNAL FORCES AND NORMAL STRESSES	49
5.1	Introduction	49
5.2	Permanent loads	68
5.2.1	Own weight of superstructure	68
5.2.2	Own weight of bridge equipment	68
5.3	Variable loads	69
5.3.1	Traffic loads	69
5.3.1.1	<i>Load model 1</i>	<i>70</i>
5.3.1.2	<i>Load model 3-3000/240 + LM1_{FRQ}</i>	<i>70</i>
5.3.1.3	<i>Load model 4</i>	<i>72</i>
5.3.1.4	<i>Load model 3 for fatigue</i>	<i>73</i>
5.3.1.5	<i>Actions on footways</i>	<i>74</i>
5.3.2	Construction load	74
5.3.3	Thermal actions.....	75
5.3.3.1	<i>Non-linear increase of temperature</i>	<i>75</i>
5.3.3.2	<i>Non-linear decrease of temperature</i>	<i>79</i>
5.4	Survey of internal forces and normal stresses	81

5.5	Combinations of actions (without prestressing)	82
5.5.1	Bending moments and normal stresses – - finished structure	82
5.5.1.1	<i>Combinations for ultimate limit states (M)</i>	83
5.5.1.2	<i>Combinations for serviceability limit states (σ)</i>	84
5.5.2	Bending moments and normal stresses – - construction stages	87
5.5.2.1	<i>Combinations for ultimate limit states (M)</i>	87
5.5.2.2	<i>Combinations for serviceability limit states (σ)</i>	87
5.5.3	Shear forces	88
5.5.4	Internal forces and normal stresses – permanent loads (finished structure)	88
5.5.4.1	<i>Design values (ULS)</i>	88
5.5.4.2	<i>Characteristic and mean values (SLS)</i>	88
5.5.5	Survey of combinations – finished structure	89
6.	PRESTRESSING	92
6.1	Introduction	92
6.2	Arrangement of prestressing reinforcement	98
6.3	Preliminary design of prestressing reinforcement	101
6.4	Detailed design of prestressing reinforcement	102
6.4.1	Initial prestressing force	102
6.4.2	Losses of prestressing force	103
6.4.2.1	<i>Losses due to friction ΔP_{μ}</i>	103
6.4.2.2	<i>Losses due to draw-in (slip) at anchorages ΔP_{sl}</i>	105
6.4.2.3	<i>Losses due to elastic deformation of concrete ΔP_{el}</i>	114
6.4.2.4	<i>Long-term losses ΔP_{c+s+r}</i>	116
7.	SERVICEABILITY LIMIT STATES	123
7.1	Stress limitation	124
7.1.1	Introduction	124
7.1.2	Check of prestressing reinforcement	125
7.1.3	Check of concrete	125
7.1.3.1	<i>Normal stresses due to permanent actions</i>	125
7.1.3.2	<i>Construction stages – transfer of prestressing</i>	126
7.1.3.3	<i>Finished structure – beginning of service</i>	128

7.1.3.4	<i>Finished structure – end of service life</i>	129
7.2	Crack control	130
7.2.1	Introduction	130
7.2.1.1	<i>Finished structure</i>	130
7.2.1.2	<i>Construction stages</i>	131
7.2.2	Check of the structure	131
7.2.2.1	<i>Construction stages – transfer of prestressing</i>	131
7.2.2.2	<i>Finished structure – beginning of service</i>	132
7.2.2.3	<i>Finished structure – end of service life</i>	132
7.3	Survey of normal stresses	132
7.4	Deformations	135
8.	ULTIMATE LIMIT STATES	135
8.1	Bending	135
8.1.1	Introduction	135
8.1.2	Detailed check of the cross section No. “5”	137
8.1.3	Simplified check of the cross section No. “5”	143
8.1.3.1	<i>Only secondary effects of thermal effects considered</i>	143
8.1.3.2	<i>Thermal effects neglected completely</i>	146
8.1.4	Prevention of brittle failure	149
8.2	Shear	152
8.2.1	Introduction	152
8.2.2	Detailing of shear reinforcement	153
8.2.3	Shear forces	153
8.2.4	Check of the member uncracked in bending at ULS	154
8.2.5	Check of the member cracked in bending at ULS	157
8.3	Fatigue	157
8.3.1	Concrete under compression	157
8.3.1.1	<i>Method acc. to EN 1992-1-1, clause 6.8.7(2)</i>	157
8.3.1.2	<i>Method acc. to EN 1992-1-1, clause 6.8.7(1)</i>	159
8.3.2	Reinforcement	161

II.	PRESTRESSED CONCRETE RAILWAY BRIDGE	162
1.	INTRODUCTION	163
2.	STRUCTURE	164
2.1	Schema of the structure	164
2.2	Process of construction	165
2.3	Properties of the full cross section	166
2.4	Effective width of flanges	167
2.5	Properties of the cross section with effective width of flanges ..	167
3.	MATERIALS	169
3.1	Concrete	169
3.1.1	Basic properties	169
3.1.2	Volume changes of concrete	170
3.1.2.1	<i>Shrinkage of concrete</i>	170
3.1.2.2	<i>Creep of concrete</i>	171
3.2	Prestressing steel	172
3.3	Reinforcing steel	173
4.	ACTIONS	173
4.1	Permanent loads	173
4.1.1	Own weight of superstructure	173
4.1.2	Own weight of bridge equipment	174
4.1.3	Uneven settlements of supports	174
4.2	Variable loads	174
4.2.1	Traffic loads	174
4.2.1.1	<i>Load model 71</i>	174
4.2.1.2	<i>Load models SW/0 and SW/2</i>	175
4.2.1.3	<i>Load model "unloaded train"</i>	176
4.2.1.4	<i>Load model "HSLM" (High Speed Load Model)</i>	176
4.2.1.5	<i>Eccentricity of vertical actions (LM71 and SW/0)</i>	176
4.2.1.6	<i>Actions on non-public footpaths</i>	176
4.2.1.7	<i>Dynamic effects</i>	176
4.2.1.8	<i>Groups of traffic loads</i>	178

4.2.2	Thermal actions	178
4.2.3	Construction load	180
4.3	Accidental actions	180
4.4	Combinations of actions	182
5.	DETERMINATION OF INTERNAL FORCES AND NORMAL STRESSES	182
5.1	Introduction	182
5.2	Influence lines	183
5.3	Three-moments' equation	186
5.4	Permanent loads	188
5.4.1	Own weight of superstructure	188
5.4.1.1	<i>Calculation with use of influence lines</i>	<i>188</i>
5.4.1.2	<i>Calculation with use of three-moments' equation</i>	<i>189</i>
5.4.2	Own weight of bridge equipment	190
5.4.3	Uneven settlements	190
5.4.3.1	<i>Settlement of the abutment A1</i>	<i>190</i>
5.4.3.2	<i>Settlement of the pier P2</i>	<i>190</i>
5.5	Variable loads	191
5.5.1	Traffic loads	191
5.5.1.1	<i>Load model 71</i>	<i>191</i>
5.5.1.2	<i>Load model SW/0</i>	<i>193</i>
5.5.2	Thermal actions.....	194
5.5.2.1	<i>Increase of temperature (upper surface warmer)</i>	<i>194</i>
5.5.2.2	<i>Decrease of temperature (lower surface warmer)</i>	<i>195</i>
5.5.3	Construction load	196
5.6	Survey of internal forces	196
5.7	Graphs of internal forces	197
5.7.1	Bending moments	197
5.7.2	Shear forces	199
5.8	Combinations of actions (without prestressing)	202
5.8.1	Bending moments – finished structure	202

5.8.1.1	<i>Combinations for ultimate limit states</i>	202
5.8.1.2	<i>Combinations for serviceability limit states</i>	205
5.8.2	<i>Bending moments – construction stages</i>	207
5.8.2.1	<i>Combinations for ultimate limit states</i>	207
5.8.2.2	<i>Combinations for serviceability limit states</i>	207
5.8.3	<i>Shear forces – finished structure (ULS)</i>	208
5.8.3.1	<i>Shear force V_0 at the abutment</i>	208
5.8.3.2	<i>Shear force V_{10L} at the left side of middle pier</i>	208
5.8.4	<i>Internal forces – own weight</i>	209
5.8.4.1	<i>Design values (ULS)</i>	209
5.8.4.2	<i>Characteristic and mean values (SLS)</i>	209
5.8.5	<i>Survey of combinations – finished structure</i>	210
5.8.6	<i>Survey of combinations – construction stages</i>	211
5.8.7	<i>Graphs of combinations</i>	211
5.8.7.1	<i>Bending moments – SLS, construction stages</i>	211
5.8.7.2	<i>Bending moments – SLS, finished structure</i>	213
5.8.8	<i>Calculation of normal stresses – finished structure</i>	215
5.8.8.1	<i>Characteristic combination</i>	215
5.8.8.2	<i>Frequent combination</i>	215
5.8.8.3	<i>Quasi-permanent combination</i>	215
5.8.9	<i>Calculation of normal stresses – construction stages</i>	216
5.8.9.1	<i>Characteristic combination</i>	216
5.8.9.2	<i>Quasi-permanent combination</i>	216

6. PRESTRESSING216

6.1 Introduction 216

6.2 Design of prestressing reinforcement 220

6.2.1 Arrangement of prestressing reinforcement220

6.2.2 Initial prestressing force224

6.2.3 Losses of prestressing force224

6.2.3.1 Losses due to friction ΔP_μ 224

6.2.3.2 Losses due to draw-in (slip) at anchorages ΔP_{sl} 225

6.2.3.3 Losses due to elastic deformation of concrete ΔP_{el} 228

6.2.3.4 Effects of prestressing after short-term losses 237

6.2.3.5	Long-term losses ΔP_{c+s+r}	239
6.2.3.6	Effects of prestressing in principal time stages	247
7.	SERVICEABILITY LIMIT STATES	252
7.1	Stress limitation	252
7.1.1	Introduction	252
7.1.2	Check of prestressing reinforcement	253
7.1.3	Check of concrete	254
7.1.3.1	Normal stresses due to permanent actions	254
7.1.3.2	Construction stages – transfer of prestressing	256
7.1.3.3	Finished structure – beginning of service	258
7.1.3.4	Finished structure – end of service life	260
7.2	Crack control	262
7.2.1	Introduction	262
7.2.2	Check of the structure	262
7.2.2.1	Construction stages – transfer of prestressing	262
7.2.2.2	Finished structure – beginning of service	263
7.2.2.3	Finished structure – end of service life	264
7.3	Survey of normal stresses	265
7.4	Deformations	271
8.	ULTIMATE LIMIT STATES	272
8.1	Bending	272
8.1.1	Introduction	272
8.1.2	Cross section No. “4” (at span)	272
8.1.2.1	Check of resistance moment	272
8.1.2.2	Check of plastification of materials	273
8.1.3	Cross section No. “4” (at span) – simplified check	275
8.1.3.1	Check of resistance moment	275
8.1.3.2	Check of plastification of materials	277
8.1.4	Cross section No. “10” (at pier)	277
8.1.4.1	Check of resistance moment	277
8.1.4.2	Check of plastification of materials	278

8.1.5	Cross section No. "10" (at pier) - simplified check	284
8.1.5.1	<i>Check of resistance moment</i>	284
8.1.6	Prevention of brittle failure – cross section "4"	287
8.1.7	Prevention of brittle failure – cross section "10"	288
8.2	Shear	289
8.2.1	Introduction	289
8.2.2	Shear forces	289
8.2.3	Check of the member uncracked in bending at ULS (V_0)	289
8.2.4	Check of the member cracked in bending at ULS (V_{10L})	293
8.2.4.1	<i>Introduction</i>	293
8.2.4.2	<i>Check for members not requiring design shear reinforcement</i>	293
8.2.4.3	<i>Check for members requiring design shear reinforcement</i>	295
8.3	Fatigue	297
8.3.1	Concrete under compression	297
8.3.1.1	<i>Method acc. to EN 1992-1-1, clause 6.8.7(2)</i>	297
8.3.1.2	<i>Method acc. to EN 1992-2, Annex NN, clause NN.3.2</i>	300
8.3.2	Prestressing steel	307
8.3.2.1	<i>Introduction</i>	307
8.3.2.2	<i>Check of fatigue for prestressing steel – cross section No. "4"</i>	310
8.3.2.3	<i>Check of fatigue for prestressing steel – cross section No. "10"</i>	312