
Contents

Foreword	xi
Preface	xv
List of Symbols	xix
Chapter 1. SOLCYP Project	1
1.1. Motivations.	1
1.2. The SOLCYP project	2
1.2.1. The ANR-SOLCYP program	3
1.2.2. The national SOLCYP project	4
1.2.3. Organization of the PN-SOLCYP	8
1.3. Content and nature of this book	9
1.4. Regulatory context.	10
1.5. Bibliography	11
Chapter 2. Scope and Field of Application of Recommendations	13
2.1. Variable loading and cyclic loading	13
2.2. Structures to which this discussion pertains	14
2.3. Effects of cyclic loading on the foundations	16
2.4. Types of piles	17
2.5. Types of soils	18
2.6. Bibliography	18

Chapter 3. Cyclic Loading	21
3.1. General	21
3.2. Characterization of cyclic loads	22
3.2.1. Regular loading: definitions	22
3.2.2. Cyclic loading of soil samples in the laboratory	23
3.2.3. Real-world cyclic loading	24
3.3. Taking account of real cyclic loading in the design process.	24
3.3.1. Principle and definitions	24
3.3.2. Counting methods.	27
3.3.3. Damage laws	27
3.4. Bibliography	38
Chapter 4. Introduction to Cyclic Degradation	41
4.1. Introduction	41
4.2. Cyclic degradation of soil properties.	41
4.2.1. Recap of the response of soils to monotonic loading	41
4.2.2. Soil response to cyclic loading.	42
4.2.3. Contour diagrams	44
4.2.4. Generalized contour diagrams	47
4.2.5. Obtaining contour diagrams for a particular soil	54
4.2.6. Cyclic degradation of the shear modulus	55
4.3. Cyclic degradation of soil–pile interfaces	59
4.3.1. General considerations on soil–pile interface tests.	59
4.3.2. SOLCYP databank on direct shear soil–pile tests	66
4.4. Cyclic degradation of pile response	70
4.4.1. Piles subjected to axial cyclic loading.	70
4.4.2. Piles subject to lateral cyclic loading	84
4.5. Appendices	91
4.5.1. Appendix 1: Program of CNL and CNS tests and parameters influencing their outcome	91
4.5.2. Appendix 2: CNS tests. Corrections to be made to the raw measurements	95
4.6. Bibliography	96
Chapter 5. SOLCYP Design Strategy	101
5.1. General methodology	101
5.2. Knowledge of loads	103
5.3. Analysis of regulatory loads	105

5.4. Criteria of cyclic severity for axial loads	106
5.4.1. Axial capacity of piles: definitions	106
5.4.2. Use of the cyclic stability diagram	107
5.4.3. Influence of soil–pile relative stiffness	114
5.5. Cyclic severity criteria for transverse loading	115
5.5.1. Case of sands	115
5.5.2. Case of clays	117
5.6. Detailed characterization of the cyclic loads	119
5.7. Cyclic pile design methods	121
5.8. Obtaining the parameters	122
5.9. Bibliography	122
Chapter 6. Behavior of Piles Subject to Cyclic Axial Loading	125
6.1. Introduction	125
6.2. Large international programs	127
6.3. Tests in clay soils	132
6.3.1. Normally consolidated to slightly overconsolidated clays.	132
6.3.2. Highly overconsolidated clays.	137
6.3.3. Comparisons of the results	144
6.4. Tests in sands	146
6.4.1. Silica sand	146
6.4.2. Carbonate soils	158
6.5. About the static load-bearing capacity	160
6.5.1. Ageing in sands	160
6.5.2. Effect of time and preshearing in clays	161
6.5.3. Softening.	162
6.5.4. Loading rate	162
6.6. Summary	163
6.7. Appendix: cyclic loading tests on piles at the Merville site	165
6.7.1. Introduction	165
6.7.2. Results obtained on two driven piles (B1 and B4).	166
6.7.3. Results obtained on bored (CFA) piles	167
6.7.4. Results obtained on bored screw piles	169
6.8. Bibliography	170
Chapter 7. Design of Piles Subjected to Cyclic Axial Loading	177
7.1. Introduction	177
7.2. General principles	178

7.3. The NGI approach	180
7.3.1. Fundamental principles	180
7.3.2. PAXCY and PAX2 programs	182
7.4. The ICL approach	184
7.4.1. Basic principle	184
7.4.2. The ABC global method	185
7.4.3. Local applications of the ABC method	188
7.5. The RATZ-CYCLOPS suite of programs	188
7.6. The SCARP program	191
7.6.1. Description of the SCARP program	191
7.6.2. Calibration of the SCARP program	195
7.7. Finite Element Method approaches	201
7.8. The SOLCYP approach for non-cohesive soils	203
7.8.1. General principles	203
7.8.2. Choice of parameters to characterize the soil–pile system	204
7.8.3. Modeling of the results of direct soil–structure shear	207
7.8.4. Modeling by the t–z envelope curve method	208
7.8.5. Modeling by the method of t–z cyclic curves (TZC software)	211
7.8.6. FEM modeling	217
7.8.7. Case of driven piles	224
7.9. Bibliography	225
Chapter 8. Behavior of Piles Subject to Cyclic Lateral Loading	233
8.1. Soil–pile interaction under lateral loading	233
8.1.1. Relative stiffness	234
8.1.2. Concept of lateral reaction	236
8.1.3. Crucial role of surface layers	236
8.2. Main experimental data	238
8.3. Available data on the effect of the cycles	240
8.3.1. Effect of cycles on the pile’s lateral displacement	240
8.3.2. Effect of cycles on the maximum bending moment in the pile	252
8.3.3. Effect of cycles on the P–y reaction curves	256
8.4. Contribution of the SOLCYP project	259
8.4.1. Context and scope of the studies conducted	259
8.4.2. Testing conditions	260
8.5. Data obtained on the effect of cycles	263
8.5.1. Case of sands	264
8.5.2. Case of clays	271

8.6. Final overview of the data on the effect of cycles.	285
8.6.1. Effects on pile head displacement	286
8.6.2. Effects on the maximum moment and the reactions in the soil	291
8.7. Bibliography	292
Chapter 9. Design of Piles Subject to Cyclic Lateral Loading	299
9.1. Recap of the current rules	300
9.2. Methodology to take account of cyclic loads	303
9.3. Taking account of the cycles by the global method SOLCYP-G	305
9.3.1. Principles of the global method	305
9.3.2. Conventional limit load and failure load	305
9.3.3. Degree of relative stiffness of the pile and limits of flexible and rigid piles	308
9.3.4. Presizing of the pile subject to the maximum static load H_{\max}	311
9.3.5. Cyclic severity criteria	314
9.3.6. Effect of cycles on the pile head displacement	315
9.3.7. Effect of cycles on the maximum bending moment	319
9.4. Taking account of cycles by a local method SOLCYP-L	319
9.4.1. Principle of the local method	319
9.4.2. Determination of the P-multipliers for monotonic P–y curves	320
9.5. Domains of validity and example of application	323
9.5.1. Domains of validity of the global method SOLCYP-G and local method SOLCYP-L	323
9.5.2. Example of application of the global and local methods	327
9.6. Conclusion	345
9.7. Bibliography	345
Chapter 10. Determination of Cyclic Parameters for Pile Design	347
10.1. Introduction	347
10.2. Parameters for the design of piles subjected to cyclic loads	348
10.2.1. Mineralogy	350
10.2.2. Parameters for monotonic calculations	351
10.2.3. Cyclic parameters	352
10.2.4. Consolidation parameters	352
10.2.5. Remolding parameters	353

10.3. Obtaining the parameters for the design of piles subjected to cyclic loading	353
10.3.1. Lab tests	353
10.3.2. In situ tests	365
10.4. Bibliography	370
Chapter 11. Recommendations for Testing Piles Under Cyclic Loading	377
11.1. Introduction	377
11.2. Reasons for the tests	378
11.3. The different test methods	379
11.4. Contribution of calibration chamber tests: Axial loading	381
11.5. Contribution of centrifuge tests: Axial or transverse loading	383
11.6. <i>In situ</i> axial loading tests	384
11.6.1. Objectives of the test	384
11.6.2. Design support tests (FEED tests)	385
11.6.3. Validation tests (Non-Working Pile Tests)	391
11.6.4. Control tests (Working Pile Tests)	393
11.7. Transverse loading tests <i>in situ</i>	394
11.7.1. Objectives and representativity of tests	394
11.7.2. Design support tests (FEED tests)	395
11.7.3. Validation tests (Non-Working Pile Tests)	399
11.7.4. Control tests (Working Pile Tests)	400
11.8. Appendix 1: Recap on scaling effects	401
11.8.1. Tests on reduced-scale models in the lab	402
11.8.2. Tests of piles <i>in situ</i>	404
11.9. Appendix 2: <i>In situ</i> axial loading	404
11.9.1. Test setup	404
11.9.2. Instrumentation and data acquisition	406
11.10. Appendix 3: Transverse loading <i>in situ</i>	409
11.10.1. Test setup	409
11.10.2. Instrumentation and data acquisition	411
11.11. Bibliography	413
Index	417