

## PART IV SUBSTRUCTURES

<b>CHAPTER 1 GENERAL</b> .....	1
1.1 Scope .....	1
1.2 Definitions .....	2
1.3 Fundamentals of Design Calculations .....	3
1.4 Conditions of Construction for Design .....	4
1.5 Items to be Shown in Drawings .....	5
<b>CHAPTER 2 SURVEY</b> .....	7
2.1 General .....	7
2.1.1 Fundamentals .....	7
2.1.2 Types of Surveys .....	7
2.2 Geotechnical Investigation .....	15
2.2.1 General .....	15
2.2.2 Preliminary Surveys .....	17
2.2.3 Principal Surveys .....	19
2.2.4 Evaluation of Geotechnical Parameters for Design .....	30
2.3 Survey of River Characteristics and Water Utilization .....	36
2.4 Survey of Construction Conditions .....	37
<b>CHAPTER 3 FUNDAMENTALS OF DESIGN</b> .....	39
3.1 General .....	39
3.2 Load Combinations in Design Calculations .....	41
3.3 Verification of Safety for Loads .....	47
<b>CHAPTER 4 ALLOWABLE STRESSES</b> .....	50
4.1 General .....	50
4.2 Allowable Stresses of Concrete .....	52
4.3 Allowable Stresses of Reinforcing Bars .....	61
4.4 Allowable Stresses of Steel Materials for Structures .....	64
4.5 Allowable Stresses of Prestressing Steel Materials .....	65

<b>CHAPTER 5 VERIFICATION OF STRUCTURAL MEMBERS</b> .....	67
5.1 Verification of Structural Members for under Ordinary, Strom, and Level 1 Earthquake Conditions. ....	67
5.1.1 General .....	67
5.1.2 Verification of RC Members Subjected to Bending Moments or Axial Forces ..	67
5.1.3 Verification of RC Members Subjected to Shear Forces .....	68
5.2 Verification of Members for Under Level 2 Earthquake Condition .....	72
5.2.1 General .....	72
5.2.2 Verification of RC Members Subjected to Bending Moments or Axial Forces ..	73
5.2.3 Verification of RC Members Subjected to Shear Forces .....	74
<b>CHAPTER 6 DURABILITY</b> .....	77
6.1 General .....	77
6.2 Examination of Salt Damage .....	78
<b>CHAPTER 7 STRUCTURAL DETAILS OF REINFORCED CONCRETE MEMBERS</b> ...	83
7.1 Scope .....	83
7.2 General .....	83
7.3 Minimum and Maximum Amount of Reinforcement .....	84
7.4 Concrete Cover for Reinforcing Steel .....	87
7.5 Spacing of Reinforcing Steels .....	88
7.6 Anchorage of Reinforcing Steel .....	89
7.7 Hook and Bent Shape of Reinforcing Steel .....	94
7.8 Joint of Reinforcing Steels .....	97
7.9 Axial Reinforcement Bar .....	100
7.10 Shear Reinforcements .....	100
<b>CHAPTER 8 DESIGN OF PIERS, ABUTMENTS, FOOTINGS, AND ABUTMENT BACK APPROACH</b> .....	107
8.1 Scope .....	107
8.2 General .....	107
8.2.1 Location, Type, and Configuration of Piers and Abutments .....	107
8.2.2 Design of Structures with Large Width .....	110

8.2.3 Protection Against Colliding Objects .....	111
8.3 Design of Piers .....	111
8.3.1 T-shaped Piers .....	111
8.3.2 Rigid-frame Piers .....	116
8.4 Design of Abutments .....	119
8.4.1 Reverse T-shaped Abutments .....	119
8.4.2 Skew Abutments .....	124
8.4.3 Design of Parapets .....	128
8.4.4 Design of Wing Walls .....	134
8.5 Substructure body -Footing Connections .....	137
8.6 Design of Bridge Seats .....	138
8.7 Footings .....	145
8.7.1 General .....	145
8.7.2 Thickness of Footings .....	146
8.7.3 Design for Bending Moments .....	149
8.7.4 Design for Shear Forces .....	154
8.7.5 Arrangement of Reinforcement .....	166
8.8 Abutment Jointless Structure .....	170
8.9 Abutment Back Approach .....	175

<b>CHAPTER 9 FUNDAMENTAL REQUIREMENTS FOR STABILIZATION OF</b>	
<b>FOUNDATIONS .....</b>	<b>182</b>
9.1 General .....	182
9.2 Basic Requirements of Design .....	186
9.3 Selection of Foundation Types .....	194
9.4 Selection of Bearing Layer and Embedment Depth Requirements .....	196
9.5 Design Ground Surface .....	202
9.6 Coefficients of Subgrade Reaction .....	205
9.6.1 General .....	205
9.6.2 Coefficients of Subgrade Reactions .....	206
9.7 Calculation of Subgrade Reaction and Displacement .....	210
9.7.1 General .....	210

9.7.2	Subgrade Reaction Elastic Displacement .....	211
9.8	Deep Foundations to be Constructed Deep in Grounds Subject to Consolidation Settlement .....	211
9.9	Foundations Subjected to Eccentric Loads .....	212
9.10	Foundations of Skewed Abutments .....	215
<b>CHAPTER 10</b>	<b>DESIGN OF SPREAD FOUNDATIONS .....</b>	<b>218</b>
10.1	Fundamentals of Design .....	218
10.2	Load Shearing .....	221
10.3	Allowable Bearing Capacity of Ground .....	222
10.3.1	Allowable Vertical Bearing Capacity of Ground below Base of Foundation ..	222
10.3.2	Allowable Horizontal Bearing Capacity of Ground .....	232
10.3.3	Allowable Shear Resistance of the Ground below the Base of a Foundation ..	232
10.4	Coefficients of Subgrade Reactions .....	236
10.5	Calculation of Subgrade Reaction Intensity and Displacement .....	239
10.6	Design of Footings .....	242
10.7	Treatment of Foundation Base and Backfill Materials .....	245
10.7.1	Foundation Base .....	245
10.7.2	Backfill Material .....	246
<b>CHAPTER 11</b>	<b>DESIGN OF A CAISSON FOUNDATION .....</b>	<b>247</b>
11.1	Basic Requirements of Design .....	247
11.2	Load Sharing .....	250
11.3	Shapes and Dimensions .....	252
11.4	Allowable Bearing Capacity of Soil Layer .....	255
11.4.1	Allowable Vertical Bearing Capacity of Soil Layer .....	255
11.4.2	Allowable Shear Resistance of Soil Layers at the Bottom of Foundation ..	262
11.4.3	Negative Skin Friction .....	262
11.5	Coefficient of Ground Reaction and Upper Limit Value of Subgrade Reaction ..	264
11.5.1	Coefficient of Ground Reaction .....	264
11.5.2	Upper Limit Value of Ground Reaction .....	268
11.6	Calculations of Sectional Force, Ground Reaction, and Displacement .....	272
11.7	Design of Various Members of Foundation .....	280

11.7.1	Caisson Side Wall and Partition	280
11.7.2	Top Slab	289
11.7.3	Top Slab Bearing Unit	292
11.7.4	Bottom Plate of Open Caisson	294
11.7.5	Cutting Edge	295
11.7.6	Ceiling Slab for Pneumatic Caisson Working Chamber and Suspended Beams for the Ceiling Slab	297
11.7.7	Parapet	299
11.7.8	Examination of Stresses during Construction	300
11.8	Verification for Level 2 Earthquake Condition	301
11.8.1	Basics of Verification	301
11.8.2	Yield of Foundation	303
11.8.3	Allowable Ductility Factor and Allowable Displacement of Foundations	305
11.8.4	Calculation of Sectional Force, Subgrade Reaction and Displacement	306
11.8.5	Verification of Members	311
11.9	Details of Structure	314
11.9.1	Construction Joint	314
11.9.2	Reinforcement around Pneumatic Caisson Shaft Holes	314
11.9.3	Arrangement of Reinforcing Bars on the Side Walls	315
<b>CHAPTER 12 DESIGN OF PILE FOUNDATIONS</b>		<b>317</b>
12.1	Fundamentals of Design	317
12.2	Load Shearing	320
12.3	Arrangement of Piles	320
12.4	Allowable Bearing Capacity of Piles	323
12.4.1	Axial Allowable push-on bearing capacity of Single Pile	323
12.4.2	Axial allowable pull-out resistance force of Single Piles	338
12.4.3	Negative Skin Friction	342
12.4.4	Consideration of Group Piles Effects	348
12.5	Coefficient of Horizontal Subgrade Reaction	351
12.6	Spring Constants of Piles	352
12.6.1	Axial Spring Constants of Piles	352
12.6.2	Radial Spring Constant of Piles	354

12.7	Calculation of Pile Reactions and Displacements	358
12.8	Design of Pile Foundation under Special Conditions	362
12.9	Design of Pile	370
12.9.1	Design of Piles against Loads after Construction	370
12.9.2	Pile Joints	373
12.9.3	Connections between Pile and Footing	374
12.9.4	Designs for Construction Period	380
12.10	Verification for Level 2 Earthquake Condition	381
12.10.1	Basics of Verification	381
12.10.2	Yielding of Foundation	383
12.10.3	Allowable Ductility Factor and Allowable Displacement of Foundation	384
12.10.4	Calculation of Sectional Force, Pile Head Reaction and Displacement	385
12.10.5	Verification of Members	393
12.11	Structural Details	396
12.11.1	PHC Piles	396
12.11.2	Cast-in-place RC Piles	399
12.11.3	Steel Pipe Piles	404
12.11.4	Steel Pipe Soil Cement Piles	410
12.11.5	SC Piles	411
<b>CHAPTER 13</b>	<b>DESIGN OF STEEL PIPE SHEET PILE FOUNDATION</b>	<b>414</b>
13.1	Basic Requirements of Design	414
13.2	Load Sharing	417
13.3	Shape and Size	418
13.4	Allowable Bearing Capacity of a Steel Pipe Sheet Pile	420
13.4.1	Allowable Bearing Capacity of a Steel Pipe Sheet Pile	420
13.4.2	Allowable Pull-out Force of a Steel Pipe Sheet Pile	422
13.4.3	Negative Skin Friction Effect of Consolidation Settlement	423
13.5	Coefficient of Ground Reaction	426
13.6	Calculation of Sectional Force, Unit Ground Reaction and Displacement	427
13.7	Design of Various Members of Foundation	434
13.7.1	Steel Pipe Sheet Pile	434

13.7.2	Top Slab	434
13.7.3	Design of Connection between Top Slab and Steel Pipe Sheet Pile	436
13.8	Cofferdam	437
13.9	Verification for Level 2 Earthquake Conditions	438
13.9.1	Basics of Verification	438
13.9.2	Yield of Foundation	438
13.9.3	Allowable Ductility Factor and Allowable Displacement of Foundation	440
13.9.4	Calculation on Sectional Force, Ground Reaction and Displacement	440
13.9.5	Verification for Strength of Members	444
13.10	Details of Structure	445
<b>CHAPTER 14 CAST-IN-SITU DIAPHRAGM WALL FOUNDATION DESIGNS</b>		<b>449</b>
14.1	Basic Requirements of Design	449
14.2	Load Sharing	452
14.3	Shape, Size, and Joint	453
14.4	Allowable Bearing Capacity of Ground	454
14.4.1	Allowable Vertical Bearing Capacity of Foundation Bed Ground	454
14.4.2	Allowable Shear Resistance of Foundation Bed Ground	455
14.4.3	Negative Skin Friction	456
14.5	Coefficient of Ground Reaction and Upper Limit Value Of Subgrade Reaction	458
14.5.1	Coefficient of Ground Reaction	458
14.5.2	Upper Limit Value of Ground Reaction	460
14.6	Calculations of Sectional Force, Ground Reaction, and Displacement	462
14.7	Design of Foundation Body	463
14.8	Verification for Level 2 Earthquakes	465
14.8.1	Principles of Verification	465
14.8.2	Yield of Foundation	466
14.8.3	Allowable Ductility Factor and Allowable Displacement of Foundation	466
14.8.4	Calculation on Section Force, Subgrade Reaction and Displacement	466
14.8.5	Verification for Strength of Members	468
14.9	Details of Structure	469
14.9.1	Joint between Elements	469

14.9.2	Connection between Cast-in-situ Diaphragm Walls and Top Slabs	470
14.9.3	Thickness of Wall	470
14.9.4	Arrangement of Reinforcing Bars	471
14.9.5	Lap splice of Vertical Reinforcing Bars	472
<b>CHAPTER 15</b>	<b>Design of Deep Foundations</b>	<b>474</b>
15.1	Basic Requirements of Design	474
15.2	Load Distribution	477
15.3	Geometries and Arrangement of Deep Foundations	481
15.4	Allowable Bearing Capacity of Ground	483
15.4.1	Allowable Vertical Unit Bearing Capacity of Foundation Bottom Ground	483
15.4.2	Allowable Shear Resistance Force of Foundation Bottom Ground	486
15.5	Coefficients of Subgrade Reaction and Upper Limits of Unit Subgrade Reaction	487
15.5.1	Coefficients of Subgrade Reaction	487
15.5.2	Upper Limit of Horizontal Unit Subgrade Reaction on Foundation Front	491
15.5.3	Upper Limits of Unit Subgrade Reaction on Foundation Side and Foundation Peripheral Surface	493
15.6	Calculation of Sectional Force, Unit Subgrade Reaction, and Displacement	495
15.7	Verification of Each Member of Foundations	497
15.7.1	Combined Deep Foundations	497
15.7.2	Cylindrical Deep Foundations	498
15.8	Verification of Performance under Level 2 Earthquake Conditions	500
15.8.1	Bases of Verification	500
15.8.2	Yield of Foundations	501
15.8.3	Calculation of Sectional Forces, Unit Subgrade Reaction, and Displacement	501
15.8.4	Verification of Members	503
15.9	Structural Details	503
15.10	Design of Earth Retaining Structure	505
<b>CHAPTER 16</b>	<b>GENERAL REQUIREMENTS ON EXECUTION OF WORK</b>	<b>508</b>
16.1	Scope	508
16.2	General Items of Construction Work	508
16.3	Survey for Construction Work	509



16.4 Execution Program .....	510
16.5 Work Record .....	512
<b>CHAPTER 17 CONSTRUCTION OF CAISSON FOUNDATION .....</b>	<b>514</b>
17.1 Method to be Applied .....	514
17.2 Selection of Construction Machines and Instruments .....	514
17.3 Cutting Edges .....	515
17.4 Installation of a Caisson .....	515
17.5 Caisson Main Body .....	516
17.6 Excavation and Sinking .....	517
17.7 Verification of Bearing Layer .....	520
17.8 Top Slab .....	522
17.9 Cut-off Walls and Temporary Retaining Walls .....	522
17.10 Center .....	523
17.11 Concrete Filling of a Pneumatic Caisson .....	524
17.12 Bottom Slab of an Open Caisson .....	525
<b>CHAPTER 18 CONSTRUCTION OF PREFABRICATED PILE FOUNDATION .....</b>	<b>527</b>
18.1 Method to be Applied .....	527
18.2 Selection of Construction Machines and Instruments .....	528
18.3 Test Piling .....	529
18.4 Preparation for Construction .....	530
18.5 Transportation, Storage, and Inspection .....	531
18.6 Installation .....	531
18.7 Site-welded Joint .....	532
18.8 Finishing of a Pile Head .....	534
18.9 Driving a Pile and Finishing the Driving Operation .....	535
18.10 Pile-boring Method .....	539
18.10.1 Excavation, Sinking and Retaining .....	539
18.10.2 Treatment of a Pile Tip .....	541
18.11 Preboring Pile Method .....	543
18.11.1 Boring .....	543
18.11.2 Formation of Soil Cement Columns .....	544

18.11.3 Sinking and Retaining .....	545
18.12 Steel Pipe and Soil Cement Composite Pile Method .....	545
18.12.1 Excavation .....	545
18.12.2 Preparation of Soil Cement Column .....	546
18.12.3 Sinking and Retaining of Steel Pipe .....	547
18.13 Screw Pile Method .....	548
<b>CHAPTER 19 CONSTRUCTION OF CAST-IN-PLACE PILE FOUNDATION .....</b>	<b>551</b>
19.1 Method to be Applied .....	551
19.2 Selection of Construction Machines and Instruments .....	552
19.3 Test Piling .....	552
19.4 Preparation for Installation .....	553
19.5 Excavation .....	554
19.6 Protection of Bore Wall from Collapse .....	555
19.7 Slime Treatment .....	557
19.8 Production and Installation of Reinforcement Cage .....	557
19.9 Concrete .....	560
<b>CHAPTER 20 CONSTRUCTION OF STEEL PIPE SHEET PILE FOUNDATION .....</b>	<b>562</b>
20.1 Method to be Applied .....	562
20.2 Test Piling .....	563
20.3 Installation of Guide Materials .....	564
20.4 Driving a Pile and Finishing the Driving Operation .....	565
20.5 Filling Concrete and Finishing of Joint Pipes .....	566
20.6 Cofferdam and Top Slab .....	567
20.6.1 Construction of a Cofferdam .....	567
20.6.2 Top Slab Connection and Top Slab .....	568
20.6.3 Removing Support Timbering and Steel Pipe Sheet Piles Acting as Cofferdam .....	569
<b>CHAPTER 21 CONSTRUCTION OF THE CAST-IN-SITU DIAPHRAGM WALL FOUNDATION .....</b>	<b>570</b>
21.1 Method to be Applied .....	570
21.2 Test Work .....	570

21.3 Preparations for Construction .....	570
21.4 Excavation .....	571
21.4.1 Element Allocation .....	571
21.4.2 Stability of Trench Walls .....	572
21.4.3 Slurry .....	572
21.4.4 Excavation .....	573
21.4.5 Slime Processing .....	574
21.5 Fabrication & Installation of Reinforcement Steel Cages .....	574
21.6 Element Joints .....	576
21.7 Concrete .....	577
<b>CHAPTER 22 CONSTRUCTION OF DEEP FOUNDATION .....</b>	<b>579</b>
22.1 Method to be Applied .....	579
22.2 Selection of Construction Machines and Instruments .....	579
22.3 Preparation for Installation .....	580
22.4 Disposal of Spring Water and Ground Water .....	580
22.5 Excavation .....	581
22.6 Retaining Walls Structure .....	582
22.7 Completion of a Bore Bottom .....	583
22.8 Reinforcement Bars .....	583
22.9 Concrete .....	585
22.10 Backfilling .....	586