# Geotechnical Engineering Handbook

**Volume 3: Elements and Structures** 

Editor: Ulrich Smoltczyk



### Contents

#### 3.1

**Spread foundations** Ulrich Smoltczyk, Dieter Netzel, and Manfred Kany

1	Definitions 1
2	Basis of design 1
3	Footings
3.1	General aspects of design 3
3.2	Geotechnical design 13
3.3	Structural design
4.	Slab foundations 46
4.1	General
4.2	Vertical interaction 46
4.3	Horizontal interaction, restraints
5	Mat foundations (tank foundations) 71
5.1	General
5.2	Geotechnical verifications
5.3	Groundwater protection
6	Tension foundations
7	References, standards and software
7.1	References
7.2	Programmes and guidebooks 80
7.3	European codes (Status 2002) 81
7.4	German standards referenced in this chapter
	*

#### 3.2 Pile foundations

Hans-Georg	Kempfert,	Kurt	Dieter	Eigenbrod,	and
Ulrich Smolt	czyk (Secti	ion 8,	)		

1	Introduction	83
1.1	Applications	83
1.2	Governing codes and safety concepts	
1.3	Preliminary investigations for pile foundations	84
1.4	Terminology	85
2	Pile types and construction methods	
2.1	Selection of appropriate pile type	
2.2	Quality assurance and control	88
2.3	Displacement piles	
2.4	Bored piles 1	104
2.5	Micropiles	
2.6	Measures to increase pile resistance	113

3	Axial pile resistance
3 3.1	Single piles
$\frac{5.1}{2.2}$	Compression pile groups
3.2	Pile-raft foundations
	The rait foundations
3.4	Tension pile groups
	Lateral pile resistance and moment actions
4.1	Single piles
	Lateral resistance of pile groups 163
5	Soil action
5.1	Negative skin friction
5.2	Lateral pressure and bending due to settlement 170
6	Bearing capacity and serviceability 173
6.1	General
6.2	Bearing capacity (ULS) 174
6.3	Calculation of serviceability 181
7	Testing of piles
7.1	General
7.2	Static axial load tests
7.3	Static horizontal pile load tests 192
7.4	Dynamic pile testing
8	Analysis of pile structures
8.1	General
8.2	Piling systems
8.3	Analysis of axially loaded pile systems
8.4	Special simple cases
8.5	Deviations from initial assumptions
8.6	Design of non-axially loaded pile foundations
8.7	Check for buckling
8.8	Sheet pile wall as part of a piled foundation
8.9	Eigenfrequencies of a spatial piling system
8.10	Example
9	Example         220           References         223
7	

#### 3.3

## **Caissons** Hans Lingenfelser

1	General
1.1	Terms
1.2	Typical features of pneumatic caissons
1.3	Typical features of open caissons (wells) 231
1.4	Fields of application 232
2	Structural concept and equipment 234
2.1	General
2.2	Construction materials
2.3	Caisson edges
2.4	Caisson working chamber and working chamber ceiling 237
2.5	Open caisson bottom
2.6	Caissons walls
3	Construction of caissons
3.1	Manufacture on land
-	

3.2	Construction in open water	242
3.3	Construction in a dock and floating in	
4	Sinking the caissons	245
4.1	Soil excavation	245
4.2	Control of sinking	247
4.3	Sinking tolerances	247
4.4	Ballasting	249
5	Pneumatic installation and works	250
5.1	Regulations governing pneumatic works	250
5.2	Essential pneumatic equipment	251
6	Caisson calculation	253
6.1	General	253
6.2	Calculation of the lowering diagram	254
6.3	Loads working on the caisson cutters	255
6.4	Dimensioning for the lowering phases	257
7	Construction examples	259
8	References	271

#### 3.4

## **Stability of excavations** Anton Weissenbach, Achim Hettler, and Brian Simpson

1	Construction measures for the stability of excavations
1.1	Unlined excavations
1.1	Timbered trenches
1.2	
1.0	Sheet pile walls
1.4	Soldier pile walls
1.5	Solid walls
1.6	Support by bracing
2	Basic design assumptions
2.1	Soil properties, loads and general rules
2.2	Active earth pressure for cantilever walls
2.3	Active earth pressure for walls supported by props and anchors 293
2.4	Active earth pressure from surcharges
2.5	Earth pressure under backfill conditions
2.6	Passive earth pressure
3	Calculation procedures
3.1	Walls with fixed earth support
3.2	Walls with free earth support 313
3.3	Multiple supported walls
3.4	Calculation using subgrade reaction
3.5	Numerical analysis
3.6	Equilibrium of vertical forces
3.7	Determination of the vertical component of the earth resistance
3.8	Equilibrium of horizontal forces in soldier pile walls
3.9	Heave of the excavation bottom
3. <del>3</del>	Safety concepts
4.1	British design approach
4.2	German design approach
4.3	General regulations in EC 7 351
4.4	Design Approach 1

4.5	Design Approach 2
5	Special constructions
5.1	Anchored walls
5.2	Excavation walls supported by raking props
5.3	Large excavations
5.4	Some features related to specific shapes of excavations
5.5	Excavation with asymmetric cross sections
5.6	Excavation walls adjacent to existing buildings
5.7	Excavations under water
5.8	Excavations in jointed, unstable rock
5.9	Excavations in soft soils 394
6	Calculation examples
6.1	Problem
6.2	German design approach 398
6.3	Eurocode 7: Design Approach 2 401
7	References

### **Bored pile walls, diaphragm walls, cut-off walls** *Manfred Stocker and Bernhard Walz* 3.5

1	Bored pile walls
1.1	Field of application
1.2	Advantages 410
1.3	Disadvantages
1.4	Standards and references 411
1.5	Purpose and wall types 411
1.6	Construction
1.7	Quality assurance
2	Diaphragm walls
2.1	Field of application
2.2	Advantages
2.3	Disadvantages
2.4	Standards and references
2.5	Purpose
2.6	Wall types
2.7	Construction
2.8	Construction materials
2.9	Characteristics
2.10	Quality assurance
3	Thin cut-off walls
3.1	Field of application
3.2	Advantages
3.3	Disadvantages
3.4	Standards and references
3.5	Purpose and types of wall
3.6	Construction of a vibrated thin cut-off wall or vibwall
3.7	Construction materials
3.8	Characteristics
3.9	Quality assurance
4	Stabilizing of earth walls using fluids
•	Submining of Cardin wants using fluids

4.1	Supporting fluids	435
4.2	Fluid supporting force and stability determination	436
4.3	Mechanisms for transferring the fluid pressure difference	
	onto the grain skeleton	437
4.4	Proof of the "internal" stability	440
4.5	Proof of the "external" stability	442
4.6	Structural facilities close to suspension stabilized earth walls	446
5	Standards and recommendations	447
5.1	Standards	447
5.2	Recommendations	448
6	References	448

### Sheet pile walls for harbours and waterways Boleslav Mazurkiewicz 3.6

1	Sheet pile wall structures, their performance and field of application 451
1.1	General
1.2	Application purpose
1.3	Usability of different construction materials
2	Regulations concerning sheet pile walls 452
2.1	Sheet pile wall structures, EN 12063/1999 452
2.2	Recommendations of the Committee for Waterfront Structures,
	Harbours and Waterways, EAU 1996 453
2.3	Eurocode 3: Design of steel structures – Part 5: Piling 453
2.4	Other recommendations and handbooks 453
3	Sheet pile types, profiles and anchoring parts, quality and steel grades 454
3.1	Steel sheet pile walls
4	Basic design of sheet pile walls 457
4.1	Safety concept
4.2	Actions and resistances
4.3	Load cases
4.4	Ultimate limit state design of sheet pile wall structures
5	Calculation methods for sheet pile walls
5.1	Calculation of a single-anchored sheet pile wall according to Blum 461
5.2	Special cases of sheet pile wall calculation
5.3	Calculation principles for combined steel sheet pile walls
5.4	Calculation principles of sheet pile cofferdams
6	Calculation of a sheet pile wall anchorage and its fittings
6.1	Verification of stability of an anchorage at a lower failure plane
	and of safety against failure of the anchoring soil
6.2	Calculation and sizing of anchor walls and anchor plates
6.3	Calculation and sizing of anchors and hinges, walings and capping
	beams made of steel and reinforced concrete
6.4	Calculation and sizing of anchor piles
6.5	Calculation and sizing of hinged and fixed supports for a quay wall
	superstructure on steel sheet pile walls
7	Further structural remarks and recommendations
7.1	Estimation of sheet pile wall driving depth and selection of its profile
	and material
7.2	Steel sheet pile walls

8	Construction of waterfront structures made of steel sheet piles 494
8.1	General
8.2	Construction of new waterfront structures 494
8.3	Protection and deepening of existing waterfront structures
9	Corrosion and corrosion protection 506
9.1	General considerations 506
9.2	Expected corrosion of steel sheet piles 506
9.3	Corrosion protection of steel sheet piles 506
10	References
10.1	Books and papers 509
10.2	Standards

#### **Gravity retaining walls** Ulrich Smoltczyk 3.7

1	Introduction	511
2	General design considerations	513
3	Gravity wall	514
4	Cantilever wall	515
5	Drainage	516
	References	

#### 3.8 **Machine foundations**

Günter Klein and Dietrich Klein

1	Overview
1.1	Classification of machine foundations
1.2	Requirements for machine foundations
2	Loads on machine foundations
2.1	Static loads
2.2	Periodic loads
2.3	Transient loads
2.4	Random loads
3	Analysis and design of machine foundations
3.1	Types of supports
3.2	Rigid foundations
3.3	Elastic foundations
3.4	Spring foundations
3.5	Design recommendations
4	Examples
4.1	Hammer foundation
4.2	Reinforced concrete box foundation for a 100 MW steam
	turbine-generator set
5	References
5.1	Standards
5.2	Books and Papers

#### Foundations in mining regions Dietmar Placzek 3.9

2Ground movements5592.1Ground movements above shallow and near-surface mine workings5633Influence of ground movements on the foundation5644.1Influence of equal vertical subsidence5643.2Influence of etilt – differential vertical subsidence5644.3Influence of strain5665.4Influence of strain5665.5Influence of discontinuous ground movements5686.6Influence of discontinuous ground movements5687.6Influence of discontinuous ground movements5684.1Types of preventive measures5684.2Basic considerations on layout and design of surface structures5694.3Bearing capacity and functionality of a structure5705.4Provisions for curvature5714.6Provisions for compressive strain5775.7Provisions for compressive strain5795.7Provisions for discontinuous ground movements5795.7Preventive measures in areas with near-surface mine workings5795.7Provisions for discontinuous ground movements5795.7Provisions for compressive strain5795.7Provisions for discontinuous ground movements5795.7Preventive measures for structures5805.3Stabilisation of the ground by injection5816Preventive measures for structures5857Upgrading of existing structures5857 <t< th=""><th>1</th><th>General remarks on mining-induced effects</th><th>559</th></t<>	1	General remarks on mining-induced effects	559
2.2       Ground movements above shallow and near-surface mine workings       563         3       Influence of ground movements on the foundation       564         3.1       Influence of equal vertical subsidence       564         3.2       Influence of equal vertical subsidence       564         3.1       Influence of equal vertical subsidence       566         3.1       Influence of curvature       566         3.1       Influence of strain       566         3.1       Influence of strain       566         3.1       Influence of ground movements above near-surface mine workings       567         3.6       Influence of discontinuous ground movements       568         4       Preventive measures in areas with deep mine workings       568         4.1       Types of preventive measures       568         4.2       Basic considerations on layout and design of surface structures       569         4.3       Provisions for curvature       570         4.4       Provisions for curvature       571         4.5       Provisions for curvature       577         7       Provisions for curvature       577         7.4       Provisions for discontinuous ground movements       579         5.7       Preventive measur	2		
2.2       Ground movements above shallow and near-surface mine workings       563         3       Influence of ground movements on the foundation       564         3.1       Influence of equal vertical subsidence       564         3.2       Influence of equal vertical subsidence       564         3.1       Influence of equal vertical subsidence       566         3.1       Influence of curvature       566         3.1       Influence of strain       566         3.1       Influence of strain       566         3.1       Influence of ground movements above near-surface mine workings       567         3.6       Influence of discontinuous ground movements       568         4       Preventive measures in areas with deep mine workings       568         4.1       Types of preventive measures       568         4.2       Basic considerations on layout and design of surface structures       569         4.3       Provisions for curvature       570         4.4       Provisions for curvature       571         4.5       Provisions for curvature       577         7       Provisions for curvature       577         7.4       Provisions for discontinuous ground movements       579         5.7       Preventive measur	2.1	Ground movements above deep mine workings	559
3Influence of ground movements on the foundation5643.1Influence of equal vertical subsidence5643.2Influence of tilt – differential vertical subsidence5643.3Influence of curvature5663.4Influence of strain5663.5Influence of ground movements above near-surface mine workings5673.6Influence of discontinuous ground movements5684Preventive measures in areas with deep mine workings5684.1Types of preventive measures5684.2Basic considerations on layout and design of surface structures5694.3Bearing capacity and functionality of a structure5704.4Provisions for tilt5704.5Provisions for curvature5714.6Provisions for compressive strain5774.7Provisions for discontinuous ground movements5795Preventive measures in areas with near-surface mine workings5795.1Types of preventive measures5795.1Types of preventive measures5805.3Stabilisation of the ground by injection5816Preventive measures for structures5846.3Stabilisation of the ground by injection5816Preventive measures for tunnels5857Upgrading of existing structures5857.1Preliminary remarks5857.2Preventive measures for tunnels5857.3Provisions for differential vertical subs	2.2		
3.1Influence of equal vertical subsidence5643.2Influence of tilt – differential vertical subsidence5643.3Influence of curvature5663.4Influence of strain5663.5Influence of ground movements above near-surface mine workings5673.6Influence of discontinuous ground movements5684Preventive measures in areas with deep mine workings5684.1Types of preventive measures5684.2Basic considerations on layout and design of surface structures5694.3Bearing capacity and functionality of a structure5704.4Provisions for curvature5714.5Provisions for curvature5714.6Provisions for curvature5714.7Provisions for compressive strain5774.8Provisions for discontinuous ground movements5795Preventive measures in areas with near-surface mine workings5795.1Types of preventive measures5795.2Preventive measures for structures5795.3Stabilisation of the ground by injection5816Preventive measures for tunnels5846.1General remarks5857Upgrading of existing structures5857Provisions for equal vertical subsidence5867.4Provisions for differential vertical subsidence5857Preventive measures for tunnels5846.1General remarks585 <td< td=""><td>3</td><td></td><td></td></td<>	3		
3.2       Influence of til – differential vertical subsidence       564         3.3       Influence of curvature       566         3.4       Influence of strain       566         3.5       Influence of ground movements above near-surface mine workings       567         3.6       Influence of discontinuous ground movements       568         4       Preventive measures in areas with deep mine workings       568         4.1       Types of preventive measures       568         4.2       Basic considerations on layout and design of surface structures       569         4.3       Bearing capacity and functionality of a structure       570         4.4       Provisions for tilt       570         4.5       Provisions for curvature       571         4.6       Provisions for extensional strain       575         4.7       Provisions for discontinuous ground movements       579         5       Preventive measures in areas with near-surface mine workings       579         5       Preventive measures for structures       570         5       Preventive measures for structures       579         5       Preventive measures for structures       579         5       Preventive measures for structures       580         5.3 <td>3.1</td> <td></td> <td></td>	3.1		
3.3Influence of curvature5663.4Influence of strain5663.5Influence of ground movements above near-surface mine workings5673.6Influence of discontinuous ground movements5684Preventive measures in areas with deep mine workings5684.1Types of preventive measures5684.2Basic considerations on layout and design of surface structures5694.3Bearing capacity and functionality of a structure5704.4Provisions for tilt5704.5Provisions for curvature5714.6Provisions for curvature5714.7Provisions for compressive strain5774.8Provisions for discontinuous ground movements5795Preventive measures in areas with near-surface mine workings5795.1Types of preventive measures5795.2Preventive measures for structures5805.3Stabilisation of the ground by injection5816Preventive measures for structures5846.1General remarks5857Upgrading of existing structures5857Provisions for differential vertical subsidence5867.3Provisions for differential vertical subsidence586	3.2		
3.4Influence of strain5663.5Influence of ground movements above near-surface mine workings5673.6Influence of discontinuous ground movements5684Preventive measures in areas with deep mine workings5684.1Types of preventive measures5684.2Basic considerations on layout and design of surface structures5694.3Bearing capacity and functionality of a structure5704.4Provisions for tilt5704.5Provisions for curvature5714.6Provisions for curvature5714.7Provisions for compressive strain5774.8Provisions for discontinuous ground movements5795Preventive measures in areas with near-surface mine workings5795.1Types of preventive measures5795.2Preventive measures for structures5805.3Stabilisation of the ground by injection5816Preventive measures for tunnels5846.1General remarks5857Upgrading of existing structures5857Provisions for differential vertical subsidence5867.3Provisions for differential vertical subsidence586	3.3		
3.6Influence of discontinuous ground movements5684Preventive measures in areas with deep mine workings5684.1Types of preventive measures5684.2Basic considerations on layout and design of surface structures5694.3Bearing capacity and functionality of a structure5704.4Provisions for tilt5704.5Provisions for curvature5714.6Provisions for extensional strain5754.7Provisions for compressive strain5774.8Provisions for discontinuous ground movements5795Preventive measures in areas with near-surface mine workings5795.1Types of preventive measures5795.2Preventive measures for structures5805.3Stabilisation of the ground by injection5816Preventive measures for tunnels5846.1General remarks5857Upgrading of existing structures5857.1Preliminary remarks5857.2Provisions for equal vertical subsidence5867.3Provisions for equal vertical subsidence5867.4Provisions for entricel subsidence5867.4Provisions for horizontal ground movements587	3.4	Influence of strain	566
3.6Influence of discontinuous ground movements5684Preventive measures in areas with deep mine workings5684.1Types of preventive measures5684.2Basic considerations on layout and design of surface structures5694.3Bearing capacity and functionality of a structure5704.4Provisions for tilt5704.5Provisions for curvature5714.6Provisions for extensional strain5754.7Provisions for compressive strain5774.8Provisions for discontinuous ground movements5795Preventive measures in areas with near-surface mine workings5795.1Types of preventive measures5795.2Preventive measures for structures5805.3Stabilisation of the ground by injection5816Preventive measures for tunnels5846.1General remarks5857Upgrading of existing structures5857.1Preliminary remarks5857.2Provisions for equal vertical subsidence5867.3Provisions for equal vertical subsidence5867.4Provisions for entricel subsidence5867.4Provisions for horizontal ground movements587	3.5	Influence of ground movements above near-surface mine workings	567
4.1Types of preventive measures5684.2Basic considerations on layout and design of surface structures5694.3Bearing capacity and functionality of a structure5704.4Provisions for tilt5704.5Provisions for curvature5714.6Provisions for extensional strain5754.7Provisions for compressive strain5774.8Provisions for discontinuous ground movements5795Preventive measures in areas with near-surface mine workings5795.1Types of preventive measures5795.2Preventive measures for structures5805.3Stabilisation of the ground by injection5816Preventive measures for tunnels5846.1General remarks5857Upgrading of existing structures5857.1Preliminary remarks5857.2Provisions for equal vertical subsidence5867.3Provisions for differential vertical subsidence5867.4Provisions for horizontal ground movements587	3.6	Influence of discontinuous ground movements	568
4.1Types of preventive measures5684.2Basic considerations on layout and design of surface structures5694.3Bearing capacity and functionality of a structure5704.4Provisions for tilt5704.5Provisions for curvature5714.6Provisions for extensional strain5754.7Provisions for compressive strain5774.8Provisions for discontinuous ground movements5795Preventive measures in areas with near-surface mine workings5795.1Types of preventive measures5795.2Preventive measures for structures5805.3Stabilisation of the ground by injection5816Preventive measures for tunnels5846.1General remarks5857Upgrading of existing structures5857.1Preliminary remarks5857.2Provisions for equal vertical subsidence5867.3Provisions for differential vertical subsidence5867.4Provisions for horizontal ground movements587	4	Preventive measures in areas with deep mine workings	568
4.3Bearing capacity and functionality of a structure5704.4Provisions for tilt5704.5Provisions for curvature5714.6Provisions for extensional strain5754.7Provisions for compressive strain5774.8Provisions for discontinuous ground movements5795Preventive measures in areas with near-surface mine workings5795.1Types of preventive measures5795.2Preventive measures for structures5805.3Stabilisation of the ground by injection5816Preventive measures for tunnels5846.1General remarks5857Upgrading of existing structures5857.1Preliminary remarks5857.2Provisions for equal vertical subsidence5867.3Provisions for horizontal ground movements586	4.1	Types of preventive measures	568
4.3Bearing capacity and functionality of a structure5704.4Provisions for tilt5704.5Provisions for curvature5714.6Provisions for extensional strain5754.7Provisions for compressive strain5774.8Provisions for discontinuous ground movements5795Preventive measures in areas with near-surface mine workings5795.1Types of preventive measures5795.2Preventive measures for structures5805.3Stabilisation of the ground by injection5816Preventive measures for tunnels5846.1General remarks5857Upgrading of existing structures5857.1Preliminary remarks5857.2Provisions for equal vertical subsidence5867.3Provisions for horizontal ground movements586	4.2	Basic considerations on layout and design of surface structures	569
4.5Provisions for curvature5714.6Provisions for extensional strain5754.7Provisions for compressive strain5774.8Provisions for discontinuous ground movements5795Preventive measures in areas with near-surface mine workings5795.1Types of preventive measures5795.2Preventive measures for structures5805.3Stabilisation of the ground by injection5816Preventive measures for tunnels5846.1General remarks5857Upgrading of existing structures5857.1Preliminary remarks5857.2Provisions for equal vertical subsidence5867.3Provisions for horizontal ground movements587	4.3		
4.5Provisions for curvature5714.6Provisions for extensional strain5754.7Provisions for compressive strain5774.8Provisions for discontinuous ground movements5795Preventive measures in areas with near-surface mine workings5795.1Types of preventive measures5795.2Preventive measures for structures5805.3Stabilisation of the ground by injection5816Preventive measures for tunnels5846.1General remarks5857Upgrading of existing structures5857.1Preliminary remarks5857.2Provisions for equal vertical subsidence5867.3Provisions for horizontal ground movements587	4.4	Provisions for tilt	570
4.7Provisions for compressive strain5774.8Provisions for discontinuous ground movements5795Preventive measures in areas with near-surface mine workings5795.1Types of preventive measures5795.2Preventive measures for structures5805.3Stabilisation of the ground by injection5816Preventive measures for tunnels5846.1General remarks5846.2Options for preventive measures5857Upgrading of existing structures5857.1Preliminary remarks5857.2Provisions for equal vertical subsidence5867.3Provisions for horizontal ground movements587	4.5	Provisions for curvature	571
4.8Provisions for discontinuous ground movements5795Preventive measures in areas with near-surface mine workings5795.1Types of preventive measures5795.2Preventive measures for structures5805.3Stabilisation of the ground by injection5816Preventive measures for tunnels5846.1General remarks5846.2Options for preventive measures5857Upgrading of existing structures5857.1Preliminary remarks5857.2Provisions for equal vertical subsidence5867.3Provisions for horizontal ground movements587	4.6	Provisions for extensional strain	575
5Preventive measures in areas with near-surface mine workings5795.1Types of preventive measures5795.2Preventive measures for structures5805.3Stabilisation of the ground by injection5816Preventive measures for tunnels5846.1General remarks5846.2Options for preventive measures5857Upgrading of existing structures5857.1Preliminary remarks5857.2Provisions for equal vertical subsidence5867.3Provisions for horizontal ground movements587	4.7	Provisions for compressive strain	577
5.1Types of preventive measures5795.2Preventive measures for structures5805.3Stabilisation of the ground by injection5816Preventive measures for tunnels5846.1General remarks5846.2Options for preventive measures5857Upgrading of existing structures5857.1Preliminary remarks5857.2Provisions for equal vertical subsidence5867.3Provisions for horizontal ground movements587	4.8	Provisions for discontinuous ground movements	579
5.2Preventive measures for structures5805.3Stabilisation of the ground by injection5816Preventive measures for tunnels5846.1General remarks5846.2Options for preventive measures5857Upgrading of existing structures5857.1Preliminary remarks5857.2Provisions for equal vertical subsidence5867.3Provisions for differential vertical subsidence5867.4Provisions for horizontal ground movements587	5	Preventive measures in areas with near-surface mine workings	579
5.3Stabilisation of the ground by injection5816Preventive measures for tunnels5846.1General remarks5846.2Options for preventive measures5857Upgrading of existing structures5857.1Preliminary remarks5857.2Provisions for equal vertical subsidence5867.3Provisions for differential vertical subsidence5867.4Provisions for horizontal ground movements587	5.1	Types of preventive measures	579
6Preventive measures for tunnels5846.1General remarks5846.2Options for preventive measures5857Upgrading of existing structures5857.1Preliminary remarks5857.2Provisions for equal vertical subsidence5867.3Provisions for differential vertical subsidence5867.4Provisions for horizontal ground movements587	5.2	Preventive measures for structures	580
6Preventive measures for tunnels5846.1General remarks5846.2Options for preventive measures5857Upgrading of existing structures5857.1Preliminary remarks5857.2Provisions for equal vertical subsidence5867.3Provisions for differential vertical subsidence5867.4Provisions for horizontal ground movements587	5.3	Stabilisation of the ground by injection	581
6.2Options for preventive measures5857Upgrading of existing structures5857.1Preliminary remarks5857.2Provisions for equal vertical subsidence5867.3Provisions for differential vertical subsidence5867.4Provisions for horizontal ground movements587	6	Preventive measures for tunnels	584
7Upgrading of existing structures5857.1Preliminary remarks5857.2Provisions for equal vertical subsidence5867.3Provisions for differential vertical subsidence5867.4Provisions for horizontal ground movements587	6.1		
7Upgrading of existing structures5857.1Preliminary remarks5857.2Provisions for equal vertical subsidence5867.3Provisions for differential vertical subsidence5867.4Provisions for horizontal ground movements587	6.2	Options for preventive measures	585
<ul> <li>7.2 Provisions for equal vertical subsidence</li></ul>	7		
<ul> <li>7.3 Provisions for differential vertical subsidence</li></ul>	7.1	Preliminary remarks	585
7.4 Provisions for horizontal ground movements 587	7.2	Provisions for equal vertical subsidence	586
	7.3		
8 References	7.4	Provisions for horizontal ground movements	587
	8	References	589

## 3.10 Watertight buildings and structures Alfred Haack and Karl-Friedrich Emig

1	General
2	General aspects of design 502
2.1	Geotechnical and structural influences 502
2.2	Serviceability provisions
3	Selection and applicability of materials 504
4	Systems
4.1	Bonded layers 505
4.2	Polymere modified bitumen compound for bonding 506
4.3	Loose plastic sheets
4.4	Steel board sealing 508

#### Contents

X	v	T
~ >		т

4.5	Watertight concrete structures ("white tub")	508
4.6	Special design considerations	
5	Design provisions codified in DIN 18195	510
5.1	General	510
6	Structural factors	513
6.1	Watertight systems according to German Code 18 195	513
6.2	Joint seals in watertight concrete	539
7	Supervision	544
8	References	545
8.2	German recommendations and guidelines (examples)	546
8.3	References	
Subj	ect index	639