actions on fasteners 2, 4, 238
anchor diameter, influence on plastic anchor 212
anchor spacing
– shear load 114–122, 170
– tension load 76–88, 152, 163, 193
anchors for autoclaved aerated concrete 33
base plate 55, 137, 153
bending of the base plate 137, 138
bond 5
bonded anchors
– description 19–25
– failure load
  – borehole cleaning 23, 187–189
  – combined tension and shear 200, 207
  – concrete breakout 200, 207
  – concrete breakout/pull-out failure 184–200
  – concrete edge breakout 200
  – environmental factors 202
  – fatigue strength 201
  – influence of temperature 190
  – load-displacement behaviour 183–189, 204
  – pry-out failure 200
  – pull-out failure 205
  – splitting of the concrete 200, 206
  – steel failure 184, 200, 205
– failure modes 181, 200
bonded anchors for crack concrete
– bonded expansion anchors 29, 208
– bonded undercut anchors 23, 208
bonded expansion anchors 208
bonded undercut anchors 23, 208
borehole cleaning 187–189
cable loop 6
cantilever bending of anchors 107–109
capacity of components in which anchors are installed
– flexural capacity 263
– overlap splice 262
– precast concrete girders and cast in-situ concrete 261
– serviceability 263
– slab without shear reinforcement 260
capsole anchor systems 19–21
carbonated concrete 255
cast-in channel
– description 7–8
– failure load
  – combined tension and shear 178
  – concrete cone breakout 165
  – concrete edge failure 170–178
  – concrete side blow-out failure 168
  – fatigue strength 179
  – load-displacement behaviour 163
  – pry-out failure 170
  – pull-out failure 168
  – splitting 169
  – steel failure 164, 170
– failure modes 163, 170
cast-in-place installation 1, 10
cast in-situ concrete layer 261
CC-method 70–137, 146–162
ceiling hanger 25, 26
clamping force 55
combined tension and shear 128, 159
– failure loads
  – bonded anchors 200, 208, 210
  – cast-in channels 178
  – headed studs 132–137, 159
  – mechanical expansion anchors 132–137, 159
  – plastic anchors 215, 222
  – power actuated fasteners 224, 226
  – undercut anchors 132–137, 159
– failure modes 128, 159, 178, 215
– load displacement behaviour 128–132, 159
concrete
– behaviour of concrete in tension 34–37
– crack process zone 37
– cracked concrete 51–54
– fracture energy 36–41
– tensile strength 35, 38, 41, 259
concrete cone breakout under tension
– characteristic of concrete failure cone 46, 49, 69, 76, 81
– crack characteristics 41, 42, 44–48
– failure load, cracked concrete 146–154, 179, 206, 234
– influence of bending moment 86–88
– influence of cracks 141–154, 179, 208, 234
– influence of eccentric tension loading 83–86
– influence of edge distance 81–83, 167
– influence of embedment depth 71, 73–75, 166, 232
– influence of reinforcement 88, 90, 153, 154, 168
– influence of spacing 76–81, 166–167, 193, 233
– load-displacement behaviour 66, 67, 143–145, 234
concrete edge breakout
– failure load, cracked concrete 158, 179, 210
– influence of bending moment 121
– influence of concrete strength 112, 113
– influence of cracks 157, 158, 179, 210
– influence of different angles between shear load and edge 125–128
– influence of eccentric shear load 120
– influence of edge distance 112, 116, 117, 120, 171
– influence of embedment depth 112
– influence of hanger reinforcement 122–125
– influence of load transfer length 112
– influence of member thickness 119, 120, 172
– influence of spacing 114–118, 170
– load-displacement behaviour 117
concrete failure cone 46, 49, 69, 76, 81, 231
concrete strength 71–76, 112, 113
corrosion of anchors 255–258
corrosion protection class 257
crack
– crack width, causes of cracking, crack types, crack appearance 51–53, 142
– influence on failure load
– bonded anchors 202–210
– cast-in channels 179
– headed studs 146–156, 158–160
– mechanical expansion anchors 146–156, 158–160
– plastic anchors 220
– power actuated fastener 225
– screw anchors 234
– undercut anchors 146–156, 158–160
– influence on load-displacement behaviour
– bonded anchors 204
– headed studs 143–146, 157
– mechanical expansion anchors 143–146, 157
– plastic anchors 220
– screw anchors 234
– undercut anchors 143–146, 157
crevice corrosion 258
degree of rotational fixity  109

design of fastenings
 – ACI 318-05 (American Concrete Institute) 330–342
 – cast-in channels (CEN, European Committee for Standardisation) 302–313
 – fatigue loads  317–320
 – fire  323–325
 – forces on anchors  271–274
 – headed fasteners  289–300
 – – CC-method (EOTA)  267–283
 – – CEN, European Committee for Standardisation  289–300
 – plastic design
 – – headed fasteners  325–330
 – – post-installed fasteners  325–330
 – post-installed fasteners – chemical systems
 – – CEN, European Committee for Standardisation  315–317
 – post-installed fasteners – mechanical systems
 – – CEN, European Committee for Standardisation  313–315
 – seismic loads  320–323
 – undercut anchors
 – – CC-method (EOTA)  267–283
 – – CEN, European Committee for Standardisation  283–300
 – verification of suitability  266–271

diamond core drill  10
drill techniques
 – diamond core drilling  10, 189
 – rotary-impact drilling  10

drilled-in systems  10

eccentricity  83–86, 120
edge distance
 – shear load  112, 116, 118, 120, 171
 – tension load  81–83, 166
elastic theory  57–61
embedment depth
 – cast-in channels  166
 – headed studs  71–76, 89, 148
 – mechanical expansion anchors  71–76, 89, 148
 – plastic anchors  213
 – screw anchors  232
 – undercut anchors  71–76, 89, 148
environmental factors, bonded anchors  202
expansion force  13
externally applied moment  87, 121

fastening systems
 – bonded Anchors  19–25, 181–210
 – bonded expansion anchors  24, 208
 – bonded undercut anchors  23, 208
 – cast-in channels  7, 8, 163–179
 – ceiling hangers  25, 26
 – headed studs  9, 65–162
 – mechanical expansion anchors  11–16, 65–162
 – plastic anchors  27–29, 211–222
 – power-actuated fasteners  30, 31, 223–226
 – screw anchors  25, 227–236
 – threaded sleeves  6, 9
 – undercut anchors  16–19, 65–162
failure load
 – bonded anchors
 – – combined tension and shear  200, 207
 – – concrete breakout  200, 206
 – – concrete breakout/pull-out failure  184–200
 – – concrete edge breakout  200
 – – pry-out failure  200
 – – pull-out failure  205
 – – splitting of the concrete  200, 206
 – – steel failure  184, 200
 – cast-in channels
 – – combined tension and shear  178
 – – concrete cone breakout  165
 – – concrete edge failure  170–178
 – – concrete side blow-out failure  168
 – – fatigue strength  179
 – – pry-out failure  170
 – – pull-out failure  168
 – – splitting  169
 – – steel failure  164, 170
 – headed studs
 – – combined tension and shear, cracked concrete  159
 – – combined tension and shear, uncracked concrete  132–137
 – – concrete cone breakout  69–93, 146–154
 – – concrete edge breakout  112–128
 – – local concrete side blow-out failure  93–97, 154
 – – pry-out failure  109–112, 158
 – – pull-out and pull-through failure  97–100, 155–157
 – – shear load, cracked concrete  158
 – – shear load, uncracked concrete  10–128
 – – shear load with lever arm  107–109
Subject Index

- splitting 100–103, 157
- steel failure 68, 105–109, 157
- tension load, cracked concrete 146–157
- tension load, uncracked concrete 68–103
- mechanical expansion anchors
  - combined tension and shear, cracked concrete 159
  - combined tension and shear, uncracked concrete 132–137
- concrete cone breakout 69–93, 146–154
- concrete edge breakout 112–128
- pry-out failure 109–112, 158
- pull-out and pull-through failure 97–100, 155–157
- shear load, cracked concrete 158
- shear load, uncracked concrete 10–128
- shear load with lever arm 107–109
- splitting 100–103, 157
- steel failure 68, 105–109, 157
- tension load, cracked concrete 146–157
- tension load, uncracked concrete 68–103
- plastic anchors
  - shear and combined tension and shear 215, 221
  - tension load 211, 220
- power actuated fasteners
  - shear and combined tension and shear 224, 226
  - tension load 223, 225
- screw anchors
  - concrete edge breakout 233
  - pry-out failure 233
  - shear load 233
  - steel failure 233
  - tension load 231, 234
- undercut anchors
  - combined shear and tension, cracked concrete 159
  - combined shear and tension, uncracked concrete 132–157
  - concrete cone breakout 69–93, 146–154
  - concrete edge breakout 112–128
  - pry-out failure 109–112, 158
  - pull-out and pull-through failure 97–100, 155–157
  - shear load, cracked concrete 158
  - shear load, uncracked concrete 10–128
- shear load with lever arm 107–109
- splitting 100–103, 157
- steel failure 68, 105–109, 157
- tension load, cracked concrete 146–157
- tension load, uncracked concrete 68–103
- failure mechanisms of fastenings
  - experimental studies 45–50
  - theoretical studies 37–45
- failure modes
  - combined tension and shear 128, 159, 178
  - shear load 103–105, 157–159, 170, 200
  - tension load 65–69, 143, 163, 181
  - bonded anchors 181
  - cast-in channels 163
  - headed studs 65–69, 138–141
  - mechanical expansion anchors 65–69, 138–141
  - screw anchors 231
  - undercut anchors 65–69, 138–141
- fatigue loading
  - bonded anchors 200, 208
  - headed studs 139–142, 162
  - mechanical expansion anchors 139–142, 162
  - screw anchors 234
  - undercut anchors 139–142, 162
- fatigue strength
  - bonded anchors 200
  - cast-in channels 179
  - headed studs 139
  - mechanical expansion anchors 139
  - screw anchors 234
  - undercut anchors 139
- findley approach 217
- finite element method (FEM) 37–45
- fire 249–254
  - characteristic tension strength 252
  - failure load 250
  - concrete cone breakout 253
  - steel failure 251
  - standard time-temperature curve 249
- fire resistance 249
- flexural capacity of a reinforced concrete member 263
- follow-up expansion 14, 144, 148, 210
- fracture energy 36–41
- friction 5
- galvanic corrosion 258
- galvanised steel 255
hanger reinforcement
  – shear load 122–125, 177
  – tension load 90, 97, 103, 168

headed studs
  – description 9
  – failure load
    – combined shear and tension, cracked concrete 159
    – combined shear and tension, uncracked concrete 132–137
    – concrete cone breakout 69–93, 146–154
    – concrete edge breakout 112–128
    – local concrete side blow-out failure 93–97, 154
    – pry-out failure 109–112, 158
    – pull-out and pull-through failure 97–100, 155–157
    – shear load, cracked concrete 158
    – shear load, uncracked concrete 10–128
    – shear load with lever arm 107–109
    – splitting 100–103, 157
    – steel failure 68, 105–109, 157
    – tension load, cracked concrete 146–157
    – tension load, uncracked concrete 68–103
  – failure modes
    – combined shear and tension 128, 159
    – shear load 103–105, 157–159
    – tension load 65–69, 146
    – load-displacement behaviour
      – combined shear and tension 128–132, 159
    – shear load 103, 157
    – sustained load 138, 160
    – tension load 66, 143–146
in-place installation 10
installation configurations
  – cast-in-place technique 2, 5
  – direct installation 29
  – drilled-in systems 10
  – post-installed 10
  – pre-positioned 10
  – stand-off 10, 11
internal forces
  – elastic theory 57–61
  – forces acting on a fixture 57
  – forces acting on an anchor 57
  – non-linear method 57–61
load angle to the edge 126
load-displacement behaviour under combined tension and shear 128–132, 159
load-displacement behaviour under shear 103, 157, 170
load-displacement behaviour under tension
  – bonded anchors 183–189, 204
  – cast-in channels 163
  – headed studs 65, 143–146
  – metal expansion anchors 65, 143–146
  – numerical investigation 42
  – plastic anchors 211, 221
  – screw anchors 234
  – undercut anchors 65, 143–146
load transfer mechanism
  – bond 5
  – friction 5
  – mechanical interlock 5
loads on anchors
  – elastic theory 57–61
  – non-linear method 61
local concrete side blow-out failure 66, 93–97, 154, 168
long-term behaviour, bonded anchors 203
mechanical expansion anchors
  – description 11–16
  – failure load
    – combined shear and tension, cracked concrete 159
    – combined shear and tension, uncracked concrete 132–137
    – concrete cone breakout 69–93, 146–154
    – concrete edge breakout 112–128
    – fatigue strength 139–142, 162, 179
    – pry-out failure 109–112, 158
    – pull-out and pull-through failure 97–100, 155–157
    – shear load, cracked concrete 158
    – shear load, uncracked concrete 10–128
    – shear load with lever arm 107–109
    – splitting 100–103, 157
    – steel failure 68, 105–109, 157
    – tension load, cracked concrete 146–157
    – tension load, uncracked concrete 68–103
  – failure modes
– load-displacement behaviour
  – combined shear and tension 128–132, 159
  – shear load 103, 157
  – sustained load 138, 160
  – tension load 66, 143–146
mechanical interlock 5
member thickness 119, 120
minimum spacing and edge distance 100, 101
moisture content of plastic sleeve 214
non-linear methods 61
numerical investigations 37–54
overlap splices 262
plastic anchors
  – autoclaved aerated concrete 28
  – description 27–29
  – failure load
    – influence of cracks 220
    – influence of embedment depth 213
    – influence of hole diameter 213
    – influence of moisture content of plastic sleeve 214
    – influence of screw insertion depth 212
    – influence of temperature 214
    – influence of the diameter of the drill bit 213
    – long-term behaviour 215–220
  – failure modes 211, 215
  – load-displacement behaviour
  – concrete breakout failure 211, 221
  – profiled nail 28
  – screw 27
plastic anchors with profiled nails 28
post-installed 10
power actuated fasteners
  – description 30–31
  – failure load
    – shear and combined tension and shear 224, 226
    – tension load 223, 225
  – pilot-hole 31
precast components with site–cast topping slab 261
pre-positioned installation 10
prestressing force 55–57
pry-out failure 105, 109–112, 158, 170, 200, 233
pull-out
  – failure load
    – bonded anchors 184–200, 205
    – bonded expansion anchors 208
    – bonded undercut anchors 208
    – cast-in channels 168
    – headed studs 97–100, 155–157
    – mechanical expansion anchors 97–100, 155–157
  – plastic anchors 211–215, 220
    – screw anchors 231
    – undercut anchors 97–100, 155–157
  – load-displacement behaviour
    – bonded anchors 183–190
    – bonded expansion anchors 208
    – bonded undercut anchors 208
    – headed studs 65, 66, 143
    – mechanical expansion anchors 65, 66, 143
  – plastic anchors 211, 220
    – undercut anchors 65, 66, 143
pull-through
  – failure load 97–100, 155–157
  – load-displacement behaviour 65–66, 143
reinforcement
  – near the surface of the concrete 88, 103
  – shear load 122–125, 177
  – tension load 88, 90, 97, 99, 103, 154, 168
re-torquing of anchors 56, 57
rochert-impact drilling 10
screw anchors 25, 227–235
screw anchors
  – description 25, 227–235
  – failure load
    – influence of embedment depth 232
    – influence of spacing 233
  – failure modes 231, 233
  – installation 227–231
screw insertion
  – influence on plastic anchor 213
seismic loading
  – behaviour of anchors 240–248
  – combined tension and shear 245
  – crack cycling 247
  – load cycle sequence 246
  – loading rate 245
  – shear cycling 242
  – tension cycling 241
shear load 101, 157, 170, 200, 207
– failure loads
  – bonded anchors 200, 207, 210
  – cast-in channels 170–178
  – headed studs 105–128, 158
  – influence of edge distance 112, 116, 117, 120, 171
  – influence of reinforcement 122–125, 177
  – influence of spacing 114, 118, 170
  – mechanical expansion anchors 105–128, 158
  – power actuated fasteners 223
  – undercut anchors 105–128, 158
– load-displacement behaviour 103, 157, 170
shear load lever arm 108
shear load with lever arm 107–109
size effect 45, 71, 112
slab without shear reinforcement 260
special mark for drill bits 10
stand-off installation 10, 11
steel failure
  – fatigue loading 139, 179
  – shear load 105–109, 157, 170, 233
  – tension load 67, 68, 146, 164, 184, 205, 231
strain gradient 35
sustained loads 138, 160, 179, 215, 224
splitting force 100, 200, 263
splitting of the concrete 67, 100–103, 157, 169, 200, 206
stress corrosion 258

T-headed bolt 8

temperature
  – bonded anchors 190
  – plastic anchors 214
tensile strength of concrete 35, 38, 41, 259
tension load
  – failure load
    – bonded anchors 184–200, 204
    – cast-in channels 164–170

– condition of the concrete 239
– seismic actions 238
– type of force 239
– failure loads
  – bonded anchors 200, 207, 210
  – cast-in channels 170–178
  – headed studs 105–128, 158
  – influence of edge distance 112, 116, 117, 120, 171
  – influence of reinforcement 122–125, 177
  – influence of spacing 114, 118, 170
  – mechanical expansion anchors 105–128, 158
  – power actuated fasteners 223
  – undercut anchors 105–128, 158
– load-displacement behaviour 103, 157, 170
– failure modes
  – bonded anchors 181
  – cast-in channels 163, 170
  – headed studs 65–68, 146
  – mechanical expansion anchors 65–68, 146
  – plastic anchors 211
  – screw anchors 231, 233
  – undercut anchors 65–68, 146
– load-displacement behaviour
  – bonded anchors 183–189, 204
  – cast-in channels 163
  – headed studs 65, 143–146
  – mechanical expansion anchors 65, 143–146
– numerical investigations 42
– plastic anchors 211, 220
– screw anchors 234
– undercut anchors 65, 143–146
threaded sleeves 6, 9
torque moment 228–230
torsional stress 120
transport anchor 6

undercut anchors
  – description 16–19
  – failure load
    – combined shear and tension, cracked concrete 159
    – combined shear and tension, uncracked concrete 132–137
    – concrete cone breakout 69–93, 146–154
    – concrete edge breakout 112–128
    – fatigue strength 139–142, 162
    – pull-out and pull-through failure 97–100, 155–157
    – pry-out failure 109–112, 158
shear load, cracked concrete 158
shear load, uncracked concrete 10–128
shear load with lever arm 107–109
splitting 100–103, 157
steel failure 68, 105–109, 157
tension load, cracked concrete 146–157
tension load, uncracked concrete 68–103

failure modes
combined shear and tension 128, 159
shear load 103–105, 157–159
tension load 65–69, 146
load-displacement behaviour 65, 66, 103, 128–132, 143–146, 157

white rust 255
zink coating 255