
INDEX

Page numbers followed by f and t indicate figures and tables, respectively.

A

- Abnormal formation pressure, 386
- Absorbers
 - shock
 - effects of, 231
 - use of, 261–263
 - vibration
 - axial mode, 265, 266f
 - natural frequencies with, 265, 266, 267–270
- Accelerometer measurements, 238
- Acidizing, 47
- Advancing well bore, in plane of drilling, 444–447
- American Society of Mechanical Engineers (ASME), 2
- Amontons-Coulomb laws, of dry friction, 317–318
- Analytical method, for reaction forces, 437–440
- Angular momentum, conservation of, 247
- Annular velocity, 99
- Annulus/hole, capacity, 415
- Anticline traps, 5
- API standards, 133, 153, 156, 157, 178
 - API collapse pressure guidelines, 353–354
 - API grades, of N80, 341
 - API gravity, 2–3
 - API RP 7G standard, 156, 167, 221
- Archimedes' principle, 134–135
- Average angle method, 425–426, 461
- Axial bit force, coupling with, 247
- Axial force vibration magnitude, 330
- Axial modes
 - damping of, 236–238
 - forced vibration of, 238–241, 242f, 243f
 - natural frequencies of, 232, 233–236

- Axial support, packaging electronic components, 332
- Axial vibrations
 - controlling, 260, 261f
 - in drillstrings, 231–246
 - damping of axial modes, 236–238
 - excitation by PDC drill bits, 246
 - forced vibration of axial modes, 238–241, 242f, 243f
 - natural frequencies of axial modes, 232, 233–236
 - overview, 231–232, 233f
 - response to force vibration device, 241, 243–245
- Azar, J. J., 33
- Azimuth angle
 - defined, 422
 - measurement, 423

B

- Balanced pressure drilling, 29
- Ball bearing, 50
- Barite, 31
- Barlow formula for burst, 350
- Beams, natural frequencies of
 - long, 255–258
 - short, 251–253
- Bearing(s)
 - design, dynamic seals in, 329–330
 - friction, regions of, 318
 - life, drill bit, environment on, 326–330
 - rolling contact, 320–321
 - temperature, 330
- Bending equations in polar coordinates, 455–457
- Bending moments, 257–258
- Bending strength ratio (BSR), 167

- Bending stresses
 in drill pipe between tool joints, 174–180
 due to buckling, 172–173
- Bentonite, 31
- Bent sub, 435
- Bernoulli's equation, 75, 78, 82, 90, 101, 117–118
- Bessel functions, 166
- Bingham and Power Law models, 31–32, 81
- Bissell, George H., 12
- Bit A and Bit B, prices of, 282–283
- Bit nozzles, 51–52
- Bit torque, 330
- Blasius approximation, 81
- Blowout preventer (BOP) stack, 19, 341, 383, 396, 397
- Boatright Kirk E., Dr., 4
- Body strength and coupling strength, 379
- Bogy, D. B., 199
- Bottom hole assembly (BHA), 32, 133, 139, 140, 160
 stabilized, 437
- Boundary film region, bearing friction, 319
- Boundary lubrication, defined, 318
- Boyles's law, 391, 392
- Breakeven curve, 280–283, 287
 Bit A and Bit B, prices of, 282–283
 overview, 280–281
- Bresse's formulation, 351–352
- Brittle fracture, downhole tool design, 299–300
- Bubble point pressure, 10; *see also*
 Reservoir evaluation
- Buckling
 on an inclined plane, 199
 bending stresses due to, 172–173
 column buckling under uniform
 compression, 195–199
 drill collar buckling, 164–166
 drill pipe, 161, 255–256
 elastic buckling of thin wall pipe,
 350–353
 force, 170
 of thin wall pipe, elastic, 350–353
 application to long cylinders, 353
 Bresse's formulation, 351–352
 overview, 350–351
- Building assemblies, 167, 439
 on hole movement, 447–448
- Bulges, 4
- Buoyancy, 134–140
 composite drillstrings, 138–140
 definition of neutral point, 136–138
 drill pipe and drill collars, 138
 hook load, 135–136
- Burst, Barlow formula for, 350
- Burst pressure
 allowable and applied, 372
 line, 368
 load line, 375
 profile, defined, 360
- Burst pressure loading, 358
 intermediate casing, 360
 production casing, 357–358
- Butane, 3
- Buttress threaded connections, 343
- C**
- Cable-tool method, 13
- Cap rock, 387
- Casing
 body, tension load in, 370
 installation of, *see* Installation, of
 casing
 modes of failure and, *see* Modes
 of failure, stresses in
 casing and
 pressure, 390, 399, 402–405
 surface, 341
- Casing collapse, tension on, 361–364
 overview, 361–363
 tension forces, 363–364
- Casing design, 339–380
 elements, 355–364
 burst pressure loading (intermediate
 casing), 360
 burst pressure loading (production
 casing), 357–358
 collapse pressure loading
 (intermediate casing),
 359
 collapse pressure loading
 (production casing),
 356–357
 factors of safety, 360–361
 overview, 355–356
 pressure loading (production
 casing), 358–359
 tension on casing collapse,
 361–364
- functions, 339

- grades, 341–343
 - connections and couplings, 342–343
 - overview, 341–342
- installation, 343–347
 - leak-off tests, 344–347, 348f
 - overview, 343–344
- operational requirements, 339–341
 - overview, 339
- production casing, 5½ in., 374–380
 - equations, 380
 - overview, 374–379
- production casing, 9⅝-in., 364–374
 - with factors of safety, 371–374
 - overview, 364, 365f
 - tension, effect of, 369–370
 - tension load in casing body and couplings, 370
 - without factors of safety, 365–369
- stresses in casing and modes of failure, 347–355
 - API collapse pressure guidelines, 353–354
 - Barlow formula for burst, 350
 - elastic buckling of thin wall pipe, 350–353
 - overview, 347
 - plastic yielding and collapse with tension, 354–355
 - tabulation of casing performance properties, 355
 - thick walled cylinder stresses, 348, 349f
 - thin wall stress equations, 349
- Cementing casing, 340–341; *see also* Casing
- Cenozoic, 1
- Center of gravity, of rotor, 254
- Chalk, 4, 5
- Challenges in downhole tool design, 317–324
 - friction and wear, 317–321
 - overview, 317–318
 - rolling contact bearings, 320–321
 - thick film lubrication, 318–319
 - vibrations on life of rolling contact bearings, 321–324
 - overview, 317
- Charpy transition temperature, 341
- Charpy V-Notch tests, 299
- Chronometer, 421
- Circular arc method, 428–430
- Circulating out, kick, 402–406
 - drillers method, 402–404
 - wait and weight method, 404–406
- Circulation pressure, mud weight on, 401
- Coal oil, 12
- Codes and standards, downhole tool design, 290
- Coefficient of friction, directional wells, 449, 450
- Coffin, 44
- Collapse pressure
 - guidelines, API, 353–354
 - loading
 - intermediate casing, 359
 - production casing, 356–357
 - loadline, 374
- Collapse with tension, plastic yielding and, 354–355
- Column buckling under uniform compression, 195–199; *see also* Buckling
- Combined stresses, downhole tool design, 293–295
- Commercial oil production, 13
- Configuring the drill collar section, 160–169
 - differential sticking, 169
 - drill collar buckling, 164–166
 - drill collar stabilization, 167–169
 - length of drill collar section, 161–164
 - physical properties of drill collars, 160–161
 - rotary shouldered drill collar connections, 166–167
- Connate water, 38
- Connections, casing, 342–343; *see also* Casing
- Conservation of angular momentum, 247
- Conventional fracing, 47; *see also* Hydraulic fracturing (or fracing)
- Conversion of strain measurements to strain and stress, 313–315
- Core tops, lobed patterns in, 238
- Cornet, 44
- Cost(s)
 - curve, for Bit B, 282
 - downhole tool design, 291, 292
 - footage, *see* Footage cost
- Coulomb-Mohr criteria of failure, 42, 44, 45, 67, 296
- Coupling(s)
 - with axial bit force, 247
 - casing, 342–343

- Coupling(s) (*cont.*)
 strength, body strength and, 379
 tension load in casing body and, 370
- Course deviation, defined, 422
- Course length (CL), defined, 422
- Cramer's rule, 176
- Curvature method
 minimum, 461–462
 radius of, 426–428, 461
- Curved section, friction in, 452–462
 application to pipe bending in dog
 legs, 457–458
 bending equations in polar
 coordinates, 455–457
 equations, 461–462
 multi-spanned beam approach, 459–461
 going into well bore, 460–461
 overview, 459
 pulling out of well bore, 459, 460
 soft pipe model, 452–454
- Cutter impulsive force, 247, 248–250
- Cylinder stresses, thick walled, 348, 349f
- Cylindrical bearings, 325
- Cylindrical roller bearing, 50
- D**
- Damping
 of axial modes, 236–238
 coefficient, 240
 factor, modal, 237
- Darcy, Henri, 38
- Darcy equation, 38, 67
- Darcy-Weisbach empirical equation, 78,
 81, 82
- Dareing, 170, 219
- Departure, defined, 422
- Design(s)
 bearing, dynamic seals in, 329–330
 casing design, *see* Casing design
 downhole tool, 290–300
 considerations, combined stresses,
 293–295
 creating design alternatives,
 291–292
 evaluating alternatives and making
 choice, 292–293
 objective, 290
 setting design specifications,
 290–291
 downhole tool, challenges in,
 317–324
 friction and wear, 317–321
 overview, 317
- drill bit, expectations and, 325–330
 bearing life, environment on,
 326–330
 dynamic seals in bearing design,
 329–330
 overview, 325
 vibration and environment on
 roller cone drill bit
 bearing life, 326–329
- production casing, 5½ in., 374–380
 equations, 380
 overview, 374–379
- production casing, 9¾-in., 364–374
 with factors of safety, 371–374
 overview, 364, 365f
 tension, effect of, 369–370
 tension load in casing body and
 couplings, 370
 without factors of safety, 365–369
- Diamond, 21
 drill bits, 50
- Differential equation for torsion motion,
 246
- Differential equation of bending, 195
- Differential pressure, intensity of well
 kick, 387
- Differential sticking, 169
- Direction, defined, 422
- Directional control, tools for, 432–440
 analytical method for reaction forces,
 437–440
 downhole drilling motors, 434–435
 jet bits, 433–434
 rotary steerable tools, 436
 stabilized bottom-hole assemblies, 437
 whipstocks, 432–433
- Directional drilling, 417–462
 applications, 418–419
 drain-hole drilling, 419
 fault drilling, 418
 inaccessible locations, 419
 multiple wells from offshore
 platforms, 418
 relief wells, 419
 salt dome drilling, 418
 sidetracking and straightening,
 418
 defined, 417
 friction in directional wells, 448–452
 coefficient of friction, 449
 curved section, 452–462
 drillstrings while tripping out,
 451–452

- overview, 448–449
- WOB, 449–451
- monitoring well bore progress, 440–448
 - advancing well bore in plane of drilling, 444–447
 - building assembly on hole movement, 447–448
 - overview, 440
 - projecting ahead, 440–441
 - tool face orientation for hole correction, 441–444
- overview, 417–418
- planning directional wells, 419–421
 - formation considerations, 419, 420f, 421
 - overview, 419, 420f
- stabilized bottom hole assemblies, 467–469
- tools for directional control, 432–440
 - analytical method for reaction forces, 437–440
 - downhole drilling motors, 434–435
 - jet bits, 433–434
 - rotary steerable tools, 436
 - stabilized bottom-hole assemblies, 437
 - whipstocks, 432–433
- well path navigation, 421–432
 - average angle method, 425–426
 - definition of terms, 422
 - DLS, 430–432
 - minimum curvature method, 428–430
 - MWD, 423–424
 - overview, 421
 - radius of curvature method, 426–428
 - tangent method of tracking well path, 424–425
 - wire line survey, 422–423
- Directional wells, friction in, 448–452
 - coefficient of friction, 449
 - curved section, 452–462
 - application to pipe bending in dog legs, 457–458
 - bending equations in polar coordinates, 455–457
 - equations, 461–462
 - multi-spanned beam approach, 459–461
 - soft pipe model, 452–454
 - drillstrings while tripping out, 451–452
 - overview, 448–449
 - WOB, 449–451
- Directional wells, planning, 419–421
 - formation considerations, 419, 420f, 421
 - overview, 419, 420f
- Distributed mass model, 269
- Dog legs, 173–174
- Dog-leg severity (DLS), 417, 430–432, 445–447
 - and fatigue, 173–174
- Dough, 226
- Downhole drilling motors, 434–435
 - footage cost using, 283–285
- Downhole tool design, 290–300
 - alternatives, creating, 291–292
 - alternatives and making choice, evaluating, 292–293
 - brittle fracture, 299–300
 - challenges in, 317–324
 - considerations, combined stresses, 293–295
 - impact loading, low and high cycle fatigue, 297–300
 - material yielding, 296
 - objective, 290
 - setting design specifications, 290–291
 - stress concentration, 295–296
 - stress corrosion cracking, 298–299
 - testing, 300
- Downhole tool design, challenges in
 - friction and wear, 317–321
 - overview, 317–318
 - rolling contact bearings, 320–321
 - thick film lubrication, 318–319
 - vibrations on life of rolling contact bearings, 321–324
 - overview, 317
- Downhole turbines, 124, 126
- Drain-hole drilling, 48, 419
- Drawworks cable, flexibility, 233
- Drift angle, defined, 422
- Drill bit(s), 14, 160
 - bearing design, 51
 - bearing life
 - environment on, 326–330
 - roller cone, vibration and environment on, 326–329
 - cleaning, hydraulics for, 23–28
 - design and expectations, 325–330
 - bearing life, environment on, 326–330

- Drill bit(s) (*cont.*)
- dynamic seals in bearing design, 329–330
 - overview, 325
 - vibration and environment on roller cone drill bit bearing life, 326–329
 - navigation, 421
 - performance, monitoring, 278–280
 - selection, 21–22
 - economics, 277–278
- Drill bit types and features, 37–70
- application to general curved profiles, 66–67
 - rows of PDC cutters, 66–67
 - summary of equations, 67
 - uniform cutter density, 66
 - heat distribution under rigid body bits, 55–65
 - curved profile, 61–65
 - formulation of pressure distribution, 57–58
 - heat rate per cutter, 58–61
 - hydraulic fracturing (or fracing), 46–49
 - drilling considerations, 49
 - formation fracture pressure, 48–49
 - historical background, 47–48
 - theories of rock failure, 49
 - natural diamond drill bits, 53–55
 - polycrystalline diamond compact (PDC) bits, 52–53
 - rock mechanics, 37–46
 - flow through porous media, 39–41
 - mechanical strength of rocks, 41–44
 - modified Mohr theory, 44–46
 - permeability, 38–39
 - porosity, 37–38
 - roller cone drill bits, 50–52
- Drill collar(s), 133, 140, 160, 161, 170
- accounting for torsion flexibility in, 249–250
 - buckling, 164–166
 - capacity, 415
 - under compression, 252
 - damping for, 241
 - deflection between stabilizers, 211–213
 - historical background, 134
 - length, effect of, 263–270
 - natural frequencies with vibration absorbers, 265, 266, 267–270
 - overview, 263–265, 266f
 - vibration absorbers (axial mode), 265, 266f
 - as lumped mass, 243, 245
 - required length, 449–450
 - stabilization, 167–169
 - stabilizers, 417
 - unbalanced, 255
- Drillers method
- circulating out kick, 402–404
 - killing well, example of, 406–408
- Drilling
- Directional, *see* Directional drilling
 - drain-hole, 419
 - fault, 418
 - salt dome, 418
 - time, 277–278
 - turbines, 331
 - well kick while, detecting, 388–390
 - break, 388
 - decrease in pump pressure, 390
 - increase in flow rate, 388
 - increase in mud pit volume, 389–390
 - overview, 388
- Drilling economics, 277–287
- breakeven curve, 280–283
 - Bit A and Bit B, prices of, 282–283
 - overview, 280–281
 - drill bit performance, monitoring, 278–280
 - drill bit selection, 277–278
 - footage cost using drilling motors, 283–285
 - overview, 277
 - premature tool failure on footage cost, effect of, 285–286
- Drilling fluids, 14, 20, 141
- Drilling instrumentation, MWD, 331–335
- overview, 331
 - packaging electronic components, 331–334
 - axial support, simple harmonic housing motion, 332
 - equations, 334–335
 - lateral support, non-periodic acceleration of housing, 333–334
- Drilling motors, 144
- footage cost using, 283–285
- Drilling mud(s), 14, 20, 73
- in annulus, volume, 401
 - defined, 387

- inside drillstring, volume, 400, 401
 - pressure, 385
 - properties, 31–32
 - weight on circulation pressure, 401
- Drilling practices, 19–34
 - development of drilling program, 33–34
 - creating design alternatives, 33
 - design specifications, 33
 - evaluating alternatives, 33–34
 - operational requirements, 33
 - summary of equations, 34
 - elements
 - bottom hole assembly (BHA), 32
 - drill bit selection, 21–22
 - drilling mud properties, 31–32
 - hydraulics for best drill bit
 - cleaning, 23–28
 - pressure balance, 28–31
 - weight on bit and rotary speed, 22–23
 - subsystems of drilling rigs, 19–21
- Drill pipe(s)
 - buckling, 161, 162, 170–173
 - capacity of, 414
 - historical background, 133–134
 - lateral mode, natural frequencies of, 257–258, 259f
- Drillstring components, 140–160
 - kelly and rotary table drive, 141–142
 - physical properties of drill pipe, 144–147
 - rotary shouldered drill pipe
 - connections, 152–156
 - selecting drill pipe size and grade, 147–149
 - strength of rotary shouldered
 - connections, 156–160
 - support of drillstring in the master
 - bushing, 149–152
 - top drive, 142–144
- Drillstring design, 33–34
- Drillstring design and operation, 133–190
 - buoyancy, 134–140
 - composite drillstrings, 138–140
 - definition of neutral point, 136–138
 - drill pipe and drill collars, 138
 - hook load, 135–136
 - configuring the drill collar section, 160–169
 - differential sticking, 169
 - drill collar buckling, 164–166
 - drill collar stabilization, 167–169
 - length of drill collar section, 161–164
 - physical properties of drill collars, 160–161
 - rotary shouldered drill collar
 - connections, 166–167
- drillstring components, 140–160
 - kelly and rotary table drive, 141–142
 - physical properties of drill pipe, 144–147
 - rotary shouldered drill pipe
 - connections, 152–156
 - selecting drill pipe size and grade, 147–149
 - strength of rotary shouldered
 - connections, 156–160
 - support of drillstring in the master
 - bushing, 149–152
 - top drive, 142–144
- historical background, 133–134
 - drill collars, 134
 - drill pipe, 133–134
 - rotary shouldered connections, 134
- operational considerations, 170–180
 - bending stresses in drill pipe
 - between tool joints, 174–180
 - dog leg severity and fatigue, 173–174
 - drill pipe buckling, 170–173
 - static failure of drill pipe, 180–183
 - combined stresses, 181–182
 - torsion loading, 180–181
 - von Mises criteria of failure, 182–183
- stretch of suspended pipe, 183–186
 - drill pipe hanging in air (linear tension), 183–184
 - drill pipe hanging in drilling mud (linear tension), 184–186
 - uniform tension, 183
 - summary of equations, 186–187
- Drillstring dynamics and vibration
 - control, 231–273
 - axial vibrations, 231–246
 - damping of axial modes, 236–238
 - excitation by PDC drill bits, 246
 - forced vibration of axial modes, 238–241, 242f, 243f
 - natural frequencies of axial modes, 232, 233–236

- Drillstring dynamics and vibration control
(*cont.*)
 overview, 231–232, 233f
 response to force vibration device,
 241, 243–245
 lateral vibrations, 250–258
 drill pipe (lateral mode), natural
 frequencies of, 257–258,
 259f
 excitation of lateral modes,
 253–255
 natural frequencies, 251–253
 natural frequencies of lateral modes
 (long beams), 255–258
 natural frequency between
 stabilizers, calculation,
 252–253
 overview, 250
 PDM, excitation by, 253–254
 unbalanced drill collars, 255
 overview, 231
 torsion vibrations in, 246–250
 accounting for torsion flexibility in
 drill collars, 249–250
 coupling with axial bit force, 247
 cutter impulsive force, 247,
 248–250
 overview, 246
 PDC gear tracking, 250
 vibration control, 258, 259–272
 axial vibrations, 260, 261f
 drill collar length, effect of, 263–270
 lateral vibrations, 270, 271
 overview, 258, 259–260
 shock absorbers, use of, 261–263
 torsion vibration mode, 270, 271f
- Drillstring response, to force vibration
 device, 241, 243–245, 246f
- Drillstrings while tripping out, friction on,
 451–452
- Dropping assemblies, 167–168, 439–440
- Dry friction, Amontons-Coulomb laws of,
 317–318
- Duhamel's integral, 333
- Duplex double acting mud pumps,
 capacity, 416
- Duplex pumps, 85
- Dynamic analysis approach, 255
- Dynamic loading, on bearing life, 323
- Dynamics, drillstring, *see* Drillstring
 dynamics and vibration control
- Dynamic seals in bearing design, 329–330
- Dynamometer, 102
- E**
- East Texas Oil Field, 14–16
- Economics, drilling, *see* Drilling economics
- E75 drill pipe, 145
- Edwin Drake's oil well, motivation for,
 12–13
- Effective tension, defined, 201–202
- Elastic buckling of thin wall pipe, 350–
 353; *see also* Buckling
 application to long cylinders, 353
 Bresse's formulation, 351–352
 overview, 350–351
- Elastic collapse pressure, 354
- Elasticity
 modulus, 313
 theory, 295
- Electronic components, packaging,
 331–334
 axial support, simple harmonic
 housing motion, 332
 equations, 334–335
 lateral support, non-periodic
 acceleration of housing,
 333–334
- Elements, of casing design, 355–364
 burst pressure loading
 intermediate casing, 360
 production casing, 357–358
 collapse pressure loading
 (intermediate casing), 359
 collapse pressure loading (production
 casing), 356–357
 factors of safety, 360–361
 overview, 355–356
 pressure loading (production casing),
 358–359
 tension on casing collapse, 361–364
 overview, 361–363
 tension forces, 363–364
- Empty hole, drillstring completely
 removed, 390
- Endurance limit
 defined, 297
 determination, 297
- Environment
 drill bit bearing life, 326–330
 roller cone drill bit bearing life, 326–329
- Environmental impact, downhole tool
 design, 290–291
- Euler bending, 351
- Euler buckling theory, 198, 199; *see also*
 Buckling
- Euler's buckling equation, 197

- Euler's equation, 205, 350
- Euler's theory, 193
- Eveleth, Jonathan G., 12
- Excitation
 - of lateral modes, 253–255
 - PDM, 253–254
 - unbalanced drill collars, 255
 - by PDC drill bits, 246
- Exploratory drilling, 4, 9
- Exposed producing formation, length of, 387
- Extreme-line threaded connections, 343
- F**
- Factors of safety (FS) method, 291
 - design without, 365–369
 - elements of casing design, 360–361
 - production casing
 - design of 5½ in., 375–377
 - design of 9⁵/₈-in., 371–374
- Farris, 48
- Fatigue, downhole tool design, 297–300
- Faults, 4
 - drilling, 418
- Fault traps, 6
- Final circulating pressure (FCP), 405, 406, 407, 408, 409
- Fish-tail drag bits, 14, 37
- Float collar, 344
- Float shoe, defined, 344
- Flow rate
 - increase in, 388
 - selection, 52
- Fluid pressure
 - stratigraphic traps and, 8
- Footage cost
 - calculation, 277–278, 279–280
 - equation, 287
 - premature tool failure on, 285–286
 - using Bit A, 281, 282
 - using drilling motors, 283–285
- Forced vibration
 - of axial modes, 238–241, 242f, 243f
 - device, drillstring response to, 241, 243–245, 246f
- Force/phase analysis, of drillstring, 260
- Formation considerations, planning
 - directional wells, 419, 420f, 421
- Formation fracture gradient, defined, 347
- Formation pressure
 - abnormal, 386
 - defined, 384
 - normal, 386
- Fracking fluid, 47
- Fractions of total volume occupied by gas
 - (n_s and n), 392–393
- Fracture pressure, 385, 387
- Freebody diagram, 195
- Frequency response curves, 241
- Friction, downhole tool design, 317–321
 - overview, 317–318
 - rolling contact bearings, 320–321
 - thick film lubrication, 318–319
 - vibrations on life of rolling contact bearings, 321–324
- Friction, in directional wells, 448–452
 - coefficient of friction, 449
 - curved section, 452–462
 - application to pipe bending in dog legs, 457–458
 - bending equations in polar coordinates, 455–457
 - equations, 461–462
 - multi-spanned beam approach, 459–461
 - soft pipe model, 452–454
 - drillstrings while tripping out, 451–452
 - overview, 448–449
 - WOB, 449–451
- Frictional flow of Newtonian fluids, 75–80
 - friction head for laminar flow, 78
 - laminar flow, 76–77
 - Reynolds number, 77
 - turbulent flow, 78–80
- Frictional flow of non-Newtonian fluids, 80–85
 - laminar flow - Bingham fluids, 80
 - laminar flow - power law model, 80–81
 - turbulent flow - non-Newtonian fluids, 81–85
- Friction head for laminar flow, 78
- G**
- G105, 146, 152
- Gas and Manufacturing Company, 13
- Gas cut mud, 391–392, 393–394
- Gas cut ratio, 391
- Gas cutting
 - defined, 391
 - on well bore pressure, 391–396
 - gas cut mud, 391–392
 - pressure distribution downhole, determination of, 394–396

- Gas cutting (*cont.*)
 pressure gradient and pressure distribution, 393–394
 relation between n_s and n , 392–393
- Gas-oil ratio (GOR), 4, 9, 10–11; *see also* Reservoir evaluation
- Gauge factor (GF), 313
- Generalized Hooke's law, 311–317
 conversion of strain measurements to strain and stress, 313–315
 overview, 311
 plain strain, theory of, 312–313
 plain stress, theory of, 311–312
 strain transducers, 315–317
- Geo-space navigation, 421
- Gladys City Oil, 13
- Goodman diagram, 178, 179, 297–298
- Grade E75, 134
- Grades, of casing, 341–343
 connections and couplings, 342–343
 overview, 341–342
- Grassi, R. C., 44
- Grease (animal fat), 318
- Greenhill, 217
- Greenhill's equations, 219, 224
- Griffin theory, of brittle fracture, 49, 299
- Guide shoe, defined, 344
- Gulf coast, 7
- H**
- Hagen-Poiseuille equation, 38, 76, 78
- Halliburton, Erle P., 14
- Halliburton Oil Well Cementing Company, 14
- Hersey number, 318
- Higgins, Patillo, 13
- High cycle fatigue, downhole tool design, 297–300
- Himalayas, 1
- Hoisting, 19
- Holding assemblies, 167, 439
- Hole correction, tool face orientation for, 441–444
- Hole movement, building assembly on, 447–448
- Hooke's law, 306
 generalized, 311–317
 conversion of strain measurements to strain and stress, 313–315
 overview, 311
 strain transducers, 315–317
 theory of plain strain, 312–313
 theory of plain stress, 311–312
- Hook load, 180
- HSI, 55, 93
- Huang, 170
- Hughes, Howard, Sr., 14
- Hughes tool, 179
- Hydraulic demands of drilling motors/turbines, 125–127
- Hydraulic fracturing (or fracing), 46–49
 drilling considerations, 49
 formation fracture pressure, 48–49
 historical background, 47–48
 theories of rock failure, 49
- Hydraulic or circulation system, 19
- Hydraulics for best drill bit cleaning, 23–28
 field application, 26–28
 maximum available hydraulic horsepower, 24–26
- Hydraulics of rotary drilling, 73–130
 example of drilling hydraulics, 94–99
 change in available horsepower with well depth, 98
 effect of liner size on available HHPa, 98–99
 frictional flow of Newtonian fluids, 75–80
 friction head for laminar flow, 78
 laminar flow, 76–77
 Reynolds number, 77
 turbulent flow, 78–80
 frictional flow of non-Newtonian fluids, 80–85
 laminar flow - Bingham fluids, 80
 laminar flow - power law model, 80–81
 turbulent flow - non-Newtonian fluids, 81–85
- fundamentals of fluid flow, 73–75
 Bernoulli Equation (1st Law), 75
 continuity of fluid flow, 74–75
 hydrostatic pressure, 73–74
- hydraulic demands of drilling motors/turbines, 125–127
- mechanical features of PDMs, 104–114
 effect of housing rotation on PDM output, 112–113
 hypocycloid motion of rotors, 113–114
 mechanics of PDMs, 108–112

- mechanics of drilling turbines, 114–125
 - affect of housing rotation on output torque and power, 118–121
 - maximum output of drilling turbines, 122–125
 - mechanics of turbines, 115–118
 - performance relationships, 122
 - mud pump power supply, 85–86
 - mud pump performance, 85–86
 - optimizing available hydraulic horsepower, 87–94
 - annular velocity requirements, 94
 - maximizing hydraulic horsepower, 88–89
 - maximizing impact force, 89–92
 - nozzle selection, 92–93
 - power demands of downhole motors, 100–103
 - performance of positive displacement motors (PDM), 102–103
 - performance testing, 102
 - power conversions, 100–102
 - summary of equations, 127
 - Hydril 2-step thread, 343
 - Hydrocarbons, properties, 2–3
 - chemical bonding, 3
 - Hydrocarbon traps, 3–8
 - anticline traps, 5
 - fault traps, 6
 - salt dome, 7–8
 - stratigraphic traps, 8
 - Hydrostatic pressure, 28, 73–74, 385
 - in gas cut mud, 393–394
 - Hydrostatic stress, 45
- I**
- Igneous rocks, 1–2
 - Impact force, 89–90
 - Impact loading, downhole tool design, 297–300
 - Impermeable cap rock, 4
 - Inaccessible locations, 419
 - Initial circulating pressure (ICP), 400, 407
 - In-place crude oil, 9
 - Installation, of casing, 343–347
 - leak-off tests, 344–347, 348f
 - overview, 343–344
 - Instrumentation, MWD, 331–335
 - overview, 331
 - packaging electronic components, 331–334
 - axial support, simple harmonic housing motion, 332
 - equations, 334–335
 - lateral support, non-periodic acceleration of housing, 333–334
 - Intensity, of well kick, 387–388
 - defined, 387
 - differential pressure, 387
 - producing formation length of exposed, 387
 - permeability, 387–388
 - Intermediate casing, 341; *see also* Casing
 - burst pressure loading, 360
 - collapse pressure loading, 359
 - Internal pressure distribution, defined, 357
- J**
- Jet bits, directional control, 433–434
- K**
- Kelly, 19, 154
 - bushing, 141, 143
 - motion, measurement, 231
 - saver sub, 142
 - Kerosene, 12
 - Killing well, example of, 406–411
 - drillers method, 406–408
 - equations, 410–411
 - wait and weight method, 408–410
 - Kill rate-kill rate pressure, 400
 - Kinematics, of stator/rotor, 254
- L**
- Lame's equation, 49, 348, 349
 - Laminar flow, 75–77
 - Bingham fluids, 80
 - friction head for, 78
 - power law model, 80–81
 - Laplace equation, 40
 - Lap welded pipe, 133
 - Lateral modes
 - excitation of, 253–255
 - natural frequencies, 257–258, 259f
 - long beams, 255–258
 - short beams, 251–253
 - Lateral support, packaging electronic components, 333–334
 - Lateral vibrations, control of, 270, 271

- Lateral vibrations, in drillstrings, 250–258
 - excitation of lateral modes, 253–255
 - PDM, 253–254
 - unbalanced drill collars, 255
 - natural frequencies
 - calculation, between stabilizers, 252–253
 - drill pipe (lateral mode), 257–258, 259f
 - lateral modes (long beams), 255–258
 - lateral modes (short beams), 251–253
 - overview, 250
 - Latitude, defined, 422
 - Lead wires, 313
 - Leak-off tests, 344–347, 348f
 - Ledgerwood, 37
 - Length
 - of drill collar section, 161–164
 - of exposed producing formation, 387
 - Life of rolling contact bearings, vibrations on, 321–324
 - Life reduction coefficient, 323
 - Limestone, 2, 4, 5
 - in anticline traps, 5
 - Lithification, 5, 7, 42
 - stratigraphic traps and, 8
 - Lobed patterns in core tops, 238
 - Local hydrostatic pressures, 347
 - Locations, inaccessible, 419
 - Long beams, natural frequencies of, 255–258
 - Long thread and coupling (LT & C), 343
 - Low cycle fatigue, downhole tool design, 297–300
 - Lubinski, A., 164, 166, 179, 180
 - Lubrication, thick film, 318–319
 - Lump mass model, 269
- M**
- Mackenzie river, 5f
 - Magnitude of kick, determining, 396–399
 - Maintenance and reliability, 289–335
 - downhole tool design, 290–300
 - alternatives, creating, 291–292
 - alternatives and making choice, evaluating, 292–293
 - brittle fracture, 299–300
 - combined stresses, 293–295
 - considerations, 293–295
 - impact loading, low and high cycle fatigue, 297–300
 - material yielding, 296
 - objective, 290
 - setting design specifications, 290–291
 - stress concentration, 295–296
 - stress corrosion cracking, 298–299
 - testing, 300
 - downhole tool design, challenges in, 317–324
 - friction and wear, 317–321
 - overview, 317
 - drill bit design and expectations, 325–330
 - bearing life, environment on, 326–330
 - dynamic seals in bearing design, 329–330
 - overview, 325
 - vibration and environment on roller cone drill bit bearing life, 326–329
 - drilling turbines, 331
 - generalized Hooke's law, 311–317
 - conversion of strain measurements to strain and stress, 313–315
 - overview, 311
 - strain transducers, 315–317
 - theory of plain strain, 312–313
 - theory of plain stress, 311–312
 - MWD instrumentation, 331–335
 - axial support, simple harmonic housing motion, 332
 - equations, 334–335
 - lateral support, non-periodic acceleration of housing, 333–334
 - overview, 331
 - packaging electronic components, 331–334
 - overview, 289–290
 - positive displacement drilling motors, 330–331
 - strain, theory of, 306–310
 - Mohr's strain circle, 309–310
 - overview, 306–307
 - principal axes of stress and strain, 310
 - transformation, 307–309
 - stress, theory of, 300–306
 - defined, 300
 - maximum normal and shear stresses, 301, 302–304

- Mohr's stress circle, 304–306
 - normal and shear stress transformations, 301
 - overview, 300, 301f
- Makeup torque, 166
- Material yielding, downhole tool design, 296
- Math model, for natural frequencies with vibration absorber, 267
- Maurer, 37
- Maximum normal and shear stresses, 301, 302–304
- Maximum normal stress criteria of failure, 42, 44–45
- Mean strength, 298
- Measured depth, defined, 422
- Measurement while drilling (MWD), 20, 33–34, 138, 139, 160
 - equipment, 290
 - instrumentation, 331–335
 - overview, 331
 - packaging electronic components, 331–334
 - well path navigation, 423–424
- Mechanical/electrical power, 20
- Mechanical features of PDMs, 104–114
 - effect of housing rotation on PDM output, 112–113
 - hypocycloid motion of rotors, 113–114
 - mechanics of PDMs, 108–112
- Mechanical strength of rocks, 41–44
 - criteria of failure for brittle materials, 42–44
- Mechanics of drilling turbines, 114–125
 - affect of housing rotation on output torque and power, 118–121
 - maximum output of drilling turbines, 122–125
 - mechanics of turbines, 115–118
 - performance relationships, 122
- Mechanics of tubulars, 193–230
 - buckling on an inclined plane, 199
 - column buckling under uniform compression, 195–199
 - effect of uniform tension/compression on beam deflection, 205–213
 - inside and outside fluid pressure combined with tension/compression, 206–213
 - review of beam theory, 193–195
 - column buckling under uniform compression, 195–199
 - summary of key equations, 227
 - synchronous whirl of rotating pipe, 213–216
 - whirl of long pipe, 214–216
- torsion buckling of pipe, 217–226
 - buckling of pipe due to torque and compression/tension, 219
 - combined effects of compression/tension and whirl on pipe stability, 224–226
 - combined effects of torque, compression, and whirl on pipe stability, 226
 - torsional buckling of long vertical pipe, 219–224
- tubular buckling due to internal pressure, 199–205
 - buckling of drill collars between stabilizers, 203–205
 - combined effects of axial force and internal/external pressures, 203
 - effective tension in pipe, 201–203
- Mesozoic, 1
- Metamorphic rocks, 2
- Methane, 3, 11
- Milled tooth bits, 50
- Minimum curvature method, 428–430, 461–462
- Miska, S. Z., 33
- Mitchell, R. F., 33
- Mixed film region, bearing friction, 319
- Modal damping factor, 237
- Mode shapes, 257–258
- Modes of failure, stresses in casing and, 347–355; *see also* Casing
 - API collapse pressure guidelines, 353–354
 - Barlow formula for burst, 350
 - elastic buckling of thin wall pipe, 350–353
 - application to long cylinders, 353
 - Bresse's formulation, 351–352
 - overview, 350–351
 - overview, 347
 - plastic yielding and collapse with tension, 354–355
 - tabulation of casing performance properties, 355
 - thick walled cylinder stresses, 348, 349f
 - thin wall stress equations, 349
- Modulus of elasticity, determination, 313
- Modulus of rigidity, determination, 313

- Mohr's circle, 294, 295f
 Mohr's strain circle, 309–310
 Mohr's stress circle, 304–306
 Moineau mechanisms, 113
 applications, 241
 Moineau pump, 105, 107
 Moineau rotor, 241
 Monitoring
 drill bit performance, 278–280
 drilling turbines, 331
 well bore progress, 440–448
 advancing well bore in plane of
 drilling, 444–447
 building assembly on hole
 movement, 447–448
 overview, 440
 projecting ahead, 440–441
 tool face orientation for hole
 correction, 441–444
- Moody diagram, 78, 82–83
 MOP, 147, 148, 149, 186
 Morgan, 178
 Motor drive torque, 169
 Motor housing, rotation of, 435
 Mud
 cutting, 161
 gas cut, 391–392, 393–394
 pit volume, increase in, 389–390
 pressure, 385
 pump power supply, 85–86
 returns, 386
- Multiple wells, from offshore platforms, 418
 Multi-spanned beam approach, 459–461
 overview, 459
 well bore
 going into, 460–461
 pulling out of, 459, 460
- MWD, *see* Measurement while drilling (MWD)
- N**
- Napthalene base oil, 3
 Natural diamonds, 37, 46, 58
 drill bits, 53–55
 Natural frequencies
 axial modes, 232, 233–236, 272
 lateral modes
 drill pipe, 257–258, 259f
 long beams, 255–258
 short beams, 251–253
 lateral vibrations, 272
 with vibration absorbers, 265, 266,
 267–270
- NC 38, 153
 NC50, 147, 155, 156, 157, 159
 Neutral point, defined, 363
 Nonconventional fracing, 47
 Non-periodic acceleration of housing,
 333–334
 Normal formation pressure, 386
 Normal strain, 306–307
 Normal stress
 maximum, 301, 302–304
 transformations, 301
- North Sea, 6
 North Slope of Alaska, 3
 Nozzle sizes, 52
 N_s and n (fractions of total volume
 occupied by gas), 392–393
- O**
- Offshore platforms, multiple wells from,
 418
 Oil formation volume factor, 10; *see also*
 Reservoir evaluation
 Oil reservoirs, unitizing, 16–17
 Operational requirements
 for casing, 339–341
 defined, 355
 Output mechanical horsepower, 117
 Overburden pressure, 42, 49
 Overburden stresses, 46
- P**
- Packaging electronic components, 331–334
 axial support, simple harmonic
 housing motion, 332
 equations, 334–335
 lateral support, non-periodic
 acceleration of housing,
 333–334
- Paleozoic, 1
 Pangaea, 1
 Paraffin base oil, 3
 Parasitic losses, 87
 Parasitic pressure losses, 95
 Pasley, 199
 PDM, *see* Positive displacement motors
 (PDM)
- Pennsylvania Rock Oil Company, 12
 Pentane, 3
 Perfect cleaning theory, 23
 Performance
 downhole tool design, 292
 requirements, 290
 drill bit, monitoring, 278–280

- Permeability, 4, 9, 11
of producing formation, 387–388
- Petroleum geology, 1–2
- Physical properties of drill collars, 160–161
- Piezoelectric transducer, 317
- Pipe bending in dog legs, application to, 457–458
- Plain strain, theory of, 312–313
- Plain stress, theory of, 311–312
- Plane of drilling, advancing well bore in, 444–447
- Planning directional wells, 419–421
formation considerations, 419, 420f, 421
overview, 419, 420f
- Plastic collapse pressure, 353–354
- Plastic viscosity (PV), 32
- Plastic yielding and collapse with tension, 354–355
- Plate tectonics, 1
- Poisson's ratio, 311
- Polar coordinates, bending equations in, 455–457
- Polycrystalline diamond compact (PDC), 21, 37, 50, 58
cutters, 46, 66–67
gear tracking, 250
- Polycrystalline diamond compact (PDC) drill bits, 52–53, 105
excitation by, 246
self-excited vibrations, 260
tooth breakage on, 247
- Porosity, 4, 9
permeability, 39
- Positive displacement motors (PDM), 23
in directional drilling, 434
drilling, 330–331
excitation by, 253–254
power consumption, 125
source of lateral vibrations, 270, 271
- Power demands of downhole motors, 100–103
performance of positive displacement motors (PDM), 102–103
performance testing, 102
power conversions, 100–102
- Power output, 117, 120
- Precambrian, 1
- Predictive maintenance, 289–290
- Premature tool failure on footage cost, effect of, 285–286
- Pressure balance, 28–31
- Pressure bomb, 9
- Pressure differential, defined, 387
- Pressure distribution, 393–394
downhole, determination of, 394–396
- Pressure drop, 117–118
across bit nozzles, 27t
calculations, 54
- Pressure gradients, 385, 393–394
- Pressure guidelines, API collapse, 353–354
- Pressure lines, 385
- Pressure loading
burst (intermediate casing), 360
collapse (intermediate casing), 359
production casing, 358–359
- Pressure pulsating tool, objective, 241
- Preventive maintenance, 289
- Principal axes of stress and strain, 310
- Producing formation
exposed, length of, 387
permeability of, 387–388
- Production casing, 341; *see also* Casing
design of 5½ in., 374–380
equations, 380
overview, 374–379
design of 9¾-in., 364–374
with factors of safety, 371–374
overview, 364, 365f
tension, effect of, 369–370
tension load in casing body and couplings, 370
without factors of safety, 365–369
pressure loading, 358–359
burst, 357–358
collapse, 356–357
- Propane, 3
- Pulling out of well bore, 459, 460
- Pull-out friction forces, 143
- Pump
fracturing fluids, 46–47
pressure, decrease in, 390
- PVT test, 9, 10
- R**
- Radius of curvature method, 426–428, 461
- Rate of penetration (ROP), 22, 31, 32, 105, 112, 160, 277–278, 279, 280, 281, 283–285, 287
- Reaction forces, analytical method for, 437–440
- Reactive maintenance, 289
- Reinhold, W. B., 152
- Reliability; *see also* Maintenance and reliability
defined, 290

- Reliability approach, downhole tool design, 291
 - Relief wells, 419
 - Removing kick, calculations used in, 399–401
 - kill rate-kill rate pressure, 400
 - mud weight on circulation pressure, 401
 - overview, 399
 - volume of drilling mud in annulus, 401
 - volume of drilling mud inside drillstring, 400, 401
 - Reservoir barrels, 11
 - Reservoir economics, 11–12; *see also* Reservoir evaluation
 - Reservoir evaluation, 9–12
 - bubble point pressure, 10
 - gas-oil ratio, 10–11
 - oil formation volume factor, 10
 - reservoir economics, 11–12
 - reservoir rock properties, 11
 - Reservoir rock, 3, 4
 - properties, 4, 9, 11; *see also* Reservoir evaluation
 - Response to force vibration device, drillstring, 241, 243–245, 246f
 - Reynolds number, 77, 81
 - Rigidity, modulus of, 313
 - Risk, of design, 292
 - Robello, G., 33
 - Roblin, M. J., 178
 - Rock-cutting tool, 14
 - Rockefeller, John D., 12–13
 - Rocketdyne's F-1 engine, 300
 - Rock fracture, 45
 - Rock mechanics, 37–46
 - flow through porous media, 39–41
 - mechanical strength of rocks, 41–44
 - modified Mohr theory, 44–46
 - permeability, 38–39
 - porosity, 37–38
 - Rock oil, 12
 - Rock salt, 7
 - Rocky Mountains, 1
 - Roller cone, 21, 37
 - bits, 260
 - drill bits, 50–52, 94, 105
 - bearing life, vibration and environment on, 326–329
 - rock bits, 51
 - Rolling contact bearings, 320–321
 - life of, 321–324
 - Rotary drilling process, 13–14
 - Rotary drive and drillstring, 19
 - Rotary power, 143
 - Rotary rigs, 14
 - Rotary shouldered connections
 - historical background, 134
 - Rotary shouldered drill collar connections, 166–167
 - Rotary steering tools (RST), 20
 - directional control, 436
 - systems, 423
 - Rotary table method, 141
 - Rotor, kinematics of, 254
- S**
- SAE 4340, 177
 - Safety, 33
 - Safety factor (FS), 147
 - Salt dome, 7–8; *see also* Hydrocarbon traps
 - drilling, 418
 - Sandstone (reservoir rock), 2, 4, 5
 - in anticline traps, 5
 - Saturn/Apollo space project, 300
 - Schuh, F., 49
 - Screw jack formula, 154–155, 167
 - SCR motor drive torque, 180
 - Sedimentary rocks, 2
 - in anticline traps, 5
 - in fault traps, 6
 - Seismic surveys, 9
 - Self-excited vibrations, 260
 - Self-exciting mechanism, 246
 - Setting design specifications, downhole tool, 290–291
 - Shale, 2, 4, 5, 47
 - Shank, 53
 - Sharp-Hughes Tool Company, 14
 - Shear strain, 307
 - Shear stress
 - maximum, 301, 302–304
 - transformations, 301
 - Shock absorbers
 - effects of, 231
 - use of, 261–263
 - Short beams, natural frequencies of, 251–253
 - Short thread and coupling (ST&C), 343
 - Shoulder separation, 159
 - Shut-in casing pressure (SICP), 402, 405
 - Shut in drill pipe pressure (SIDPP), 407
 - Shut-in well, U-tube representation of, 399

- Sidetracking, 418
- Silliman, Benjamin, Jr., 12
- Simple harmonic housing motion,
 packaging electronic
 components, 332
- Slack-off friction forces, 143
- Sleeve bearings, 50, 325
- Slip crushing load, 150
- Society of Petroleum Institute (SPE), 2
- Soft pipe model, 452–454
- Source rock, 3
- Southwell, 226
- Spindletop, 31
 defined, 384
 oil field, 13–14
- Spiri, W. H., 152
- Spudding, defined, 340
- Stabilized bottom-hole assemblies, 437,
 467–469
- Stabilizers, 138, 140, 167, 199
 calculation of natural frequency
 between, 252–253
- Standard Oil Company, 13
- Standpipe pressure, 402
- Static analysis approach, 255
- Static failure of drill pipe, 180–183
 combined stresses, 181–182
 torsion loading, 180–181
 von Mises criteria of failure, 182–183
- Stator, kinematics of, 254
- Steady load, 322
- Steel billet, 133
- Stock tank barrel, 12
- Straightening, 418
- Strain gauges
 angular orientation, 315
 basic construction of, 313
 orientation of, 315
 Wheatstone bridge circuits, 313–314
- Strains, theory of, 306–310
 conversion of strain measurements to
 strain and stress, 313–315
 Mohr's strain circle, 309–310
 overview, 306–307
 plain, 312–313
 principal axes of stress and strain, 310
 transformation, 307–309
- Strain transducers, 315–317
- Stratigraphic traps, 8
- Strength properties of various rocks, 41
- Stress concentration, downhole tool
 design, 295–296
- Stress corrosion cracking, 298–299, 341
- Stresses
 in casing and modes of failure,
 347–355
 API collapse pressure guidelines,
 353–354
 Barlow formula for burst, 350
 elastic buckling of thin wall pipe,
 350–353
 overview, 347
 plastic yielding and collapse with
 tension, 354–355
 tabulation of casing performance
 properties, 355
 thick walled cylinder stresses, 348,
 349f
 thin wall stress equations, 349
 theory of, 300–306
 conversion of strain measurements
 to strain and stress,
 313–315
 defined, 300
 maximum normal and shear
 stresses, 301, 302–304
 Mohr's stress circle, 304–306
 normal and shear stress
 transformations, 301
 overview, 300, 301f
 plain, 311–312
 principal axes, 310
- Structural strength of rock, definition, 42
- Surface casing, 341; *see also* Casing
- Surface mud pumps, 19
- Swivel assembly, 144
- T**
- Tabulation of casing performance
 properties, 355
- Tangent method, of tracking well path,
 424–425
- Tar sands, 3
- Tensile strength, of API connections, 343
- Tension
 on casing collapse, 361–364
 forces, 363–364
 overview, 361–363
 effect of, 369–370, 378–379
 forces, in casing, 363–364
 load in casing body and couplings,
 370
 plastic yielding and collapse with,
 354–355
- Testing, downhole tool design, 300
- Texas-Louisiana Gulf Coast, 48

- TFA, 54
- The North Dayton Salt Dome, 8
- Theory of strain, 306–310
- Mohr's strain circle, 309–310
 - overview, 306–307
 - plain, 312–313
 - principal axes of stress and strain, 310
 - transformation, 307–309
- Theory of stress, 300–306
- defined, 300
 - maximum normal and shear stresses, 301, 302–304
 - Mohr's stress circle, 304–306
 - normal and shear stress transformations, 301
 - overview, 300, 301f
 - plain, 311–312
- Thick film
- lubrication, 318–319
 - region, bearing friction, 318
- Thick walled cylinder stresses, 348, 349f
- Thin film lubrication region, bearing friction, 319
- Thin wall pipe, elastic buckling of, 350–353
- application to long cylinders, 353
 - Bresse's formulation, 351–352
 - overview, 350–351
- Thin wall stress equations, 349
- Tool face orientation for hole correction, 441–444
- Tool joints, 153
- Tools for directional control, 432–440
- analytical method for reaction forces, 437–440
 - downhole drilling motors, 434–435
 - jet bits, 433–434
 - rotary steerable tools, 436
 - stabilized bottom-hole assemblies, 437
 - whipstocks, 432–433
- Tooth brakeage, on PDC drill bits, 247
- Torsion buckling of pipe, 217–226
- buckling of pipe due to torque and compression/ tension, 219
 - combined effects of compression/ tension and whirl on pipe stability, 224–226
 - combined effects of torque, compression, and whirl on pipe stability, 226
 - torsional buckling of long vertical pipe, 219–224
- Torsion flexibility in drill collars, 249–250
- Torsion motion, differential equation for, 246
- Torsion vibration mode, 270, 271f
- Torsion vibrations, in drillstrings, 246–250
- accounting for torsion flexibility in drill collars, 249–250
 - coupling with axial bit force, 247
 - cutter impulsive force, 247, 248–250
 - overview, 246
 - PDC gear tracking, 250
- Total flow area (TFA), 92, 433–434
- Tracking well path, tangent method of, 424–425
- Training Consultants International, 4
- Transducers, strain, 315–317
- Transformations
- normal and shear stress, 301
 - strain, 307–309
- Transition collapse pressure, 354
- Tree resin, 12
- Triplex mud pumps, capacity, 416
- Triplex pumps, 85, 86
- Tubular buckling due to internal pressure, 199–205; *see also* Buckling
- buckling of drill collars between stabilizers, 203–205
 - combined effects of axial force and internal/external pressures, 203
 - effective tension in pipe, 201–203
- Tungsten carbide, 52
- insert cutters, 50
- Turbines, 23
- drilling, 331
- Turbulent flow, 75–76, 78–80
- non-Newtonian fluids, 81–85
- U**
- Unbalanced drill collars, 255
- Uniaxial stress tests, 42
- Uniform cutter density, 66
- Up-sets, 147
- U-tube representation of shut-in well, 399
- V**
- Vertical depth, defined, 422
- Vibration(s)
- Axial, *see* Axial vibrations
 - forced
 - of axial modes, 238–241, 242f, 243f
 - device, drillstring response to, 241, 243–245, 246f

- lateral, *see* Lateral vibrations
- on life of rolling contact bearings, 321–324
- magnitude, axial force, 330
- on roller cone drill bit bearing life, 326–329
- torsion, in drillstrings, *see* Torsion vibrations, in drillstrings
- Vibration absorbers
 - axial mode, 265, 266f
 - natural frequencies with, 265, 266, 267–270
- Vibration control, 258, 259–272; *see also* Drillstring dynamics and vibration control
 - axial vibrations, 260, 261f
 - drill collar length, effect of, 263–270
 - absorbers (axial mode), 265, 266f
 - natural frequencies with vibration absorbers, 265, 266, 267–270
 - overview, 263–265, 266f
 - lateral vibrations, 270, 271
 - overview, 258, 259–260
 - shock absorbers, use of, 261–263
 - torsion vibration mode, 270, 271f
- Vibration isolation theory, 332
- Volume of drilling mud
 - in annulus, 401
 - inside drillstring, 400, 401
- von Mises criteria of failure, 145, 152, 181, 182–183, 354
- W**
- Wait and weight method
 - circulating out kick, 404–406
 - killing well, example of, 408–410
- Wear, downhole tool design, 317–321
 - overview, 317–318
 - rolling contact bearings, 320–321
 - thick film lubrication, 318–319
 - vibrations on life of rolling contact bearings, 321–324
- Webb, 217, 218
- Wedging effect, 45–46
- Weight on bit (WOB), 31, 58, 59, 63, 108, 116, 134, 137–138, 160, 161, 168, 170, 171, 198, 199
 - friction on, 449–451
 - and rotary speed, 22–23
- Well bore
 - coming out of, 390
 - going into, 390–391, 460–461
 - inclination and direction, 421
 - pressure, gas cutting on, 391–396
 - gas cut mud, 391–392
 - pressure distribution downhole, determination of, 394–396
 - pressure gradient and pressure distribution, 393–394
 - relation between n_s and n , 392–393
 - progress, monitoring, 440–448
 - advancing well bore in plane of drilling, 444–447
 - building assembly on hole movement, 447–448
 - overview, 440
 - projecting ahead, 440–441
 - tool face orientation for hole correction, 441–444
 - pulling out of, 459, 460
- Wellbore pressure, 29
- Well control, 19–20, 383–411
 - annulus/hole, capacity, 415
 - circulating out kick, 402–406
 - drillers method, 402–404
 - wait and weight method, 404–406
 - defined, 383
 - detecting well kick while drilling, 388–390
 - decrease in pump pressure, 390
 - drilling break, 388
 - increase in flow rate, 388
 - increase in mud pit volume, 389–390
 - overview, 388
 - drill collars, capacity, 415
 - drilling mud pressure, 385
 - drill pipe, capacity, 414
 - duplex double acting mud pumps, capacity, 416
 - formation pressure, 384, 386
 - fracture pressure, 385, 387
 - gas cutting on well bore pressure, 391–396
 - gas cut mud, 391–392
 - pressure distribution downhole, determination of, 394–396
 - pressure gradient and pressure distribution, 393–394
 - relation between n_s and n , 392–393
 - intensity, of well kick, 387–388
 - defined, 387
 - differential pressure, 387

- Well control (*cont.*)
- length of exposed producing formation, 387
 - permeability of producing formation, 387–388
 - killing well, example of, 406–411
 - drillers method, 406–408
 - equations, 410–411
 - wait and weight method, 408–410
 - magnitude of kick, determining, 396–399
 - overview, 383–384
 - removing kick, calculations used in, 399–401
 - kill rate-kill rate pressure, 400
 - mud weight on circulation pressure, 401
 - overview, 399
 - volume of drilling mud in annulus, 401
 - volume of drilling mud inside drillstring, 400, 401
 - taking kick while making trip, 390–391
 - empty hole, drillstring completely removed, 390
 - going into well bore, 390–391
 - well bore, coming out of, 390
 - triplex mud pumps, capacity, 416
 - U-tube representation of shut-in well, 399
 - work sheet, 414
- Well depth, 33
- Well kick
- circulating out, 402–406
 - drillers method, 402–404
 - wait and weight method, 404–406
 - intensity, 387–388
 - defined, 387
 - differential pressure, 387
 - length of exposed producing formation, 387
 - permeability of producing formation, 387–388
 - magnitude, determining, 396–399
 - removing, calculations used in, 399–401
 - kill rate-kill rate pressure, 400
 - mud weight on circulation pressure, 401
 - overview, 399
 - volume of drilling mud in annulus, 401
 - volume of drilling mud inside drillstring, 400, 401
 - taking, while making trip, 390–391
 - empty hole, drillstring completely removed, 390
 - going into well bore, 390–391
 - well bore, coming out of, 390
 - while drilling, detecting, 388–390
 - decrease in pump pressure, 390
 - drilling break, 388
 - increase in flow rate, 388
 - increase in mud pit volume, 389–390
 - overview, 388
- Well path navigation, 421–432
- average angle method, 425–426
 - definition of terms, 422
 - DLS, 430–432
 - minimum curvature method, 428–430
 - MWD, 423–424
 - overview, 421
 - radius of curvature method, 426–428
 - tangent method of tracking well path, 424–425
 - wire line survey, 422–423
- Well paths, 33
- types of, 419
- Whale oil, 12
- Wheatstone bridge configuration, 313
- Whipstocks, directional control, 432–433
- Wire line survey, 422–423
- Woodbine formation, 15
- Woods, 166
- World oil prices, 3
- Wrought iron, 133
- X**
- X95, 146, 148, 178
- Y**
- Yergin, 20–21
- Yield strength, 296
- Z**
- Zamora, 94