

# TABLE OF CONTENTS

## 1 INTRODUCTION

1.1	Historic development.....	1
1.2	Railways.....	1
1.3	Tramways and metro.....	3
1.4	Operational aspects.....	4
1.4.1	Functions of a railway company.....	4
1.4.2	Infrastructure.....	4
1.4.3	Rolling stock.....	5
1.4.4	Personnel.....	5
1.4.5	Electrification.....	6
1.4.6	Catenary systems.....	7
1.4.7	Road crossings.....	8
1.4.8	Major rail infrastructure projects.....	9
1.4.9	Developing countries.....	9
1.5	Geometry of a railway line.....	10
1.5.1	Clearances.....	10
1.5.2	Alignment.....	13
1.6	General track considerations.....	13
1.6.1	Track requirements.....	13
1.6.2	Load-bearing function of the track.....	14
1.6.3	Indication of rail forces and displacements.....	15
1.6.4	Track geometry components .....	15

## 2 WHEEL-RAIL INTERFACE

2.1	Wheel-rail guidance.....	17
2.2	Wheelset and track dimensions .....	17
2.3	Conicity.....	18
2.4	Lateral movement of a wheelset on straight track.....	19
2.4.1	Theory according to Klingel.....	19
2.4.2	Hunting movement.....	20
2.5	Equivalent conicity.....	21
2.6	Worn wheel profiles.....	22
2.7	Wheel-rail contact stresses.....	23
2.7.1	Hertz theory.....	23
2.7.2	Hertz spring constant.....	24
2.7.3	Single and two-point contact between wheel and rail.....	25
2.7.4	Spreading forces.....	26
2.7.5	Wheel-rail creep.....	27
2.7.6	Spin.....	28
2.7.7	Creepage coefficients.....	29
2.8	Train resistances.....	30
2.8.1	Types of resistances.....	30
2.8.2	Required pulling force.....	31
2.8.3	Adhesion force.....	32

## 3 CURVES AND GRADIENTS

3.1	General considerations.....	35
-----	-----------------------------	----

5.2 Curvature and superelevation in horizontal curves .....	35
3.2.1 Curve radius/curvature.....	35
3.2.2 Curve effects.....	35
5.3 Superelevation.....	36
3.3.1 General considerations.....	36
3.3.2 Cant deficiency.....	37
3.3.3 Effect of suspension on lateral acceleration .....	38
3.3.4 Effect of body tilt coaches on cant deficiency.....	38
3.3.5 Switches and other constraints.....	39
3.3.6 Cant excess.....	39
3.3.7 Maximum cant.....	39
5.4 Transition curves.....	39
3.4.1 General remarks.....	39
3.4.2 Clothoid.....	40
3.4.3 Cubic parabola.....	41
3.4.4 Curve displacement.....	41
5.5 Cross level transitions .....	42
3.5.1 Relation with the transition curve.....	42
3.5.2 Length of normal transition curve.....	43
3.5.3 Adjacent curves.....	43
5.6 Curve resistance.....	43
5.7 Gradients.....	44
3.7.1 Gradient resistance.....	44
3.7.2 Magnitude of gradient.....	44
3.7.3 Vertical transition curves.....	45
3.7.4 Guidelines for permissible quasi-static accelerations.....	45
5.8 Alignment in mountainous areas.....	46
5.9 Computer-aided track design .....	48
5.10 PASCOM - software to estimate passenger comfort.....	51
3.10.1 Numerical model.....	51
3.10.2 Case 1: Investigation of dynamic effects.....	52
3.10.3 Case 2: Track HSL-Zuid (NL).....	53

## 4 TRACK LOADS

4.1 In general.....	55
4.2 Axle loads.....	55
4.3 Line classification.....	55
4.4 Tonnages.....	56
4.5 Speeds.....	56
4.6 Causes and nature of track loads.....	57
4.7 Vertical rail forces.....	57
4.7.1 Total vertical wheel load.....	57
4.7.2 Tilting risk.....	58
4.8 Lateral forces on the rail.....	59
4.8.1 Total lateral wheel load .....	59
4.8.2 Derailment risk.....	59
4.8.3 Lateral force on the track.....	60
4.9 Longitudinal forces.....	61
4.9.1 Causes.....	61
4.9.2 Temperature forces.....	61
4.9.3 Track creep.....	61

4.9.4 Sinking load.....	62
4.10 Influence of higher speeds and increased axle loads .....	62
4.10.1 Sipaed.....	62
4.1Qj2 increase in axle loads.....	63
4.11 WheelKflats.....	67
4.12 Forces due to bad welds.....	68
4.13 Axle box accelerations.....	69
<b>5 STATIC TRACK DESIGN</b>	
5.1 Introduction.....	71
5.2 Supporting models.....	71
5.2.1 Winkler support model.....	71
5.2.2 Discrete rail support.....	71
5.2.3 Exercise: Spring constant determination.....	72
5.2.4 Continuous rail support.....	73
5.2.5 Approximation of discrete rail support.....	73
5.3 Beam on elastic foundation model.....	74
5.3.1 Solution of the differential equation.....	74
5.3.2 Several wheel loads.....	76
5.3.3 Two-axle bogie.....	77
5.3.4 Negative deflection.....	77
5.3.5 Beam with hinge (jointed track).....	78
5.3.6 Alternative expressions for characteristic length L .....	79
5.3.7 Fast determination of vertical elasticity constants.....	79
5.3.8 Order of magnitude of elasticity constants.....	79
5.4 Double beam model.....	80
5.5 Pasternak foundation model.....	81
5.6 Rail stresses.....	83
5.6.1 Stresses in rail foot centre .....	83
5.6.2 Dynamic amplification factor.....	83
5.6.3 Maximum bending stress in rail foot centre.....	84
5.6.4 Stresses in the rail head .....	86
5.6.5 Rail stresses due to a combined Q/Y load.....	88
5.6.5.1 Rail tables.....	90
5.7 Sleeper stresses.....	91
5.7.1 bed and formation.....	91
5.8 Stresses on ballast bed and formation .....	92
5.8.1 Stresses on ballast bed and formation .....	92
5.8.2 Vertical stress on ballast bed.....	92
5.8.3 Vertical stress on formation.....	93
5.8.4 Odmarks equivalence method.....	93
5.8.5 Classification of the quality of soils.....	96
5.9 Some analytical exercises.....	97
5.9.1 Fatigue rail foot .....	97
5.9.2 Fatigue rail head.....	97
5.9.3 Sleeper.....	98
5.9.4 Ballast bed.....	98
5.9.5 Temperature effects.....	98
5.10 Computer models.....	100
5.10.1 GEOTRACK program.....	100
5.10.2 The ANSYS program.....	102
5.11 Two Cases ERS'-designs.....	104

5.11.1 Testing of the UIC54 ERS .....	104
5.11.2 Testing of the SA42 ERS.....	105
5.11.3 Input and output of static model.....	106
5.11.4 Results.....	106

## 6 DYNAMIC TRACK DESIGN

6.1 Introduction.....	107
6.2 Dynamic principles .....	108
6.2.1 In general.....	108
6.2.2 One-mass spring system.....	108
6.2.3 Wheel/rail forces due to damped rail joints .....	112
6.2.4 Track excitation origins.....	113
6.3 Track modelling .....	113
6.3.1 General considerations.....	113
6.3.2 Transfer function between track load and track displacement.....	113
6.3.3 Beam on an elastic foundation.....	114
6.3.4 Discrete support.....	121
6.4 Vertical wheel response.....	121
6.4.1 Hertzian contact spring.....	121
6.4.2 Transfer functions between wheel and rail.....	122
6.5 Linear vehicle model.....	124
6.5.1 Schematisation.....	124
6.5.2 Response to irregularities in level.....	125
6.5.3 Combination of level results.....	128
6.5.4 Response to irregularities in alignment.....	129
6.5.5 Response to irregularities in cant.....	129
6.5.6 Combination of cant results .....	131
6.5.7 ISO weighting of car body accelerations.....	132
6.5.8 Calculated transfer functions for the NS measuring coach.....	133
6.6 Estimate of transfer functions using measured data .....	137
6.6.1 General concept.....	137
6.6.2 Basic principles for 1 input and 1 output.....	137
6.6.3 Multiple input single output (MISO).....	140
6.6.4 Statistical reliability.....	141
6.6.5 Numerical aspects.....	143
6.6.6 Applications.....	144
6.6.7 Comparison between transfer functions estimated by MISO and calculated with models.....	151
6.7 Vehicle response analysis in real time.....	152
6.8 Relation between Sperling's Ride Index Wz and ISO-weighted accelerations.....	155
6.9 Applications of advanced dynamic models.....	157
6.9.1 Introduction.....	157
6.9.2 The RAIL-model.....	157
6.9.3 A comparison of several different track types.....	158
6.9.4 Transitions in railway track on embankments and bridges .....	162
6.10) Track response to a moving axle load.....	164
6.10.1 Track response at the critical train velocity .....	164
6.10.2 Dynamic response of a ballast layer.....	167
6.10.3 Stiffness transitions.....	168
6.10.4 Brief discussion.....	170

## 7 TRACK STABILITY AND LONGITUDINAL FORCES

7.1 Introduction.....	171
7.1.1 Straight track and elastic lateral resistance.....	172
7.1.2 Track with misalignment and constant lateral shear resistance.....	174
7.2 Track stability: finite element modelling.....	176
7.2.1 General considerations.....	176
7.2.2 Finite element model.....	176
7.2.3 Results.....	180
7.2.4 Continuous welded switches.....	183
7.3 Longitudinal forces: analytical modelling.....	184
7.3.1 General considerations.....	184
7.3.2 Axial rail model.....	184
7.3.3 Modelling of the longitudinal interaction problem.....	186
7.4 Longitudinal forces: finite element modelling .....	189
7.4.1 General considerations.....	189
7.4.2 Finite element model.....	189
7.4.3 Examples of longitudinal force calculations.....	191
7.5 Advanced numerical models of track buckling .....	194
7.5.1 Introduction.....	194
7.5.2 Analysis of track behaviour using CWERRI.....	195
7.5.3 Analysis of longitudinal forces.....	195
7.5.4 Track lateral behaviour.....	197
7.5.5 Vertical stability of track .....	198
7.5.6 Buckling mechanism.....	198
7.5.7 Approach in order to determine the allowable temperature TALL.....	199
7.5.8 Study case: Stability of tram track.....	201

## 8 BALLASTED TRACK

8.1 Introduction.....	203
8.2 Formation.....	204
8.3 Ballast bed.....	205
8.4 Rails.....	206
8.4.1 Functions.....	206
8.4.2 Profile types.....	206
8.4.3 Geometry of flat-bottom rail.....	207
8.5 Rail joints and welds.....	208
8.5.1 Introduction.....	208
8.5.2 Fishplated joints.....	208
8.5.3 Expansion joints and expansion devices.....	209
8.5.4 Bridge transition structures.....	210
8.5.5 Insulated joint.....	210
8.6 Sleepers.....	212
8.6.1 Introduction.....	212
8.6.2 Timber sleepers.....	213
8.6.3 Concrete sleepers.....	214
8.6.4 Steel sleepers.....	216
8.7 Improvements in ballasted tracks.....	216
8.7.1 Introduction.....	216
8.7.2 Wide sleeper.....	217
8.7.3 Frame sleeper.....	218

8.7.4 Local ballast stabilisation by means of a chemical binder.....	219
8.8 Fastening systems.....	219
8.8.1 Introduction.....	219
8.8.2 Subdivision of fastenings.....	220
8.8.3 Baseplates.....	220
8.8.4 Elastic fastenings.....	221
8.8.5 Rail pads.....	222
8.9 Track on structures with a continuous ballast bed and sleepers.....	223
8.9.1 Ballast mats .....	223
8.10 Reinforcing layers.....	225
8.11 Level crossings.....	226
8.12 Tramway Track.....	227
8.12.1 Tramway track characteristics.....	227
8.12.2 Examples of paved-in tramway track.....	229
8.13 Crane Track.....	230

## 9 SLAB TRACK

9.1 Introduction.....	231
9.2 Ballasted track versus slab track.....	231
9.2.1 Ballasted track.....	232
9.2.2 Slab track.....	232
9.3 Designs of slab track superstructures .....	233
9.4 Sleepers or blocks embedded in concrete .....	234
9.4.1 Rheda 2000 .....	235
9.4.2 Zublin.....	242
9.5 Structures with asphalt-concrete roadbed .....	245
9.6 Prefabricated slabs.....	246
9.6.1 Shinkansen slab track.....	247
9.6.2 Recent design of Shinkansen slab track.....	248
9.6.3 Bögl slab track.....	251
9.7 Monolithic slabs and civil structures.....	252
9.8 Embedded Rail.....	253
9.8.1 The characteristics of embedded rail.....	253
9.8.2 Construction of embedded rail track.....	254
9.8.3 Experiences with embedded rail.....	255
9.8.4 DeckTrack.....	257
9.9 Flexural stiff slabs on top of soft soil.....	258
9.10 Clamped and continuously supported rail structures.....	261
9.10.1 CoconTrack.....	261
9.10.2 Continuously supported grooved rail.....	263
9.10.3 Web-clamped rails.....	264
9.11 EPS as subbase material in railway slab track structures .....	265
9.11.1 Introduction .....	265
9.11.2 Slab track structures with an EPS subbase .....	265
9.11.3 Static performance.....	265
9.11.4 Dynamic performance.....	266
9.11.5 Applications.....	267
9.12 Track resilience .....	267
9.13 System requirements.....	268
9.13.1 Requirements for the substructure.....	269
9.13.2 Requirements for slab track in tunnels.....	271

9.13.3 Requirements for slab track on bridges.....	271
9.13.4 Requirements for transitions.....	272
9.14 General experiences with slab track systems .....	273
9.15 Maintenance statistics of slab track.....	274

## 10 THE RAIL

10.1 Introduction.....	275
10.2 Modern rail manufacturing.....	275
10.2.1 Blastfurnace.....	275
10.2.2 Steel-making.....	277
10.2.3 Vacuum degassing and argon flushing.....	279
10.2.4 Continuous casting.....	279
10.2.5 Rolling mill.....	281
10.2.6 Finishing shop.....	282
10.2.7 Inspection and acceptance.....	286
10.2.8 Rail profiles.....	288
10.2.9 Indication of profile types according to CEN.....	288
10.3 Rail properties.....	292
10.3.1 Metallurgical fundamentals.....	292
10.3.2 Heat treatment.....	294
10.3.3 Rail grades.....	296
10.3.4 Wear resistance.....	299
10.3.5 Fatigue strength.....	300
10.3.6 Fracture mechanics.....	300
10.4 Rail welding .....	306
10.4.1 Introduction.....	306
10.4.2 Flash butt welding.....	306
10.4.3 Post-processing of flash butt welds in the NS welding depot .....	309
10.4.4 Thermit welding.....	310
10.4.5 Cooling rates.....	314
10.4.6 Improvement of weld geometry.....	316
10.4.7 Weld geometry standards.....	316
10.5 Rail failures.....	317
10.5.1 Defects in fail ends .....	317
10.5.2 Defects away from rail ends.....	318
10.5.3 Weld and resurfacing defects .....	323
10.5.4 Rail defect statistics.....	326

## 11 SWITCHES AND CROSSINGS

11.1 The standard turnout.....	333
11.1.1 Set of switches.....	334
11.1.2 Common crossing.....	335
11.1.3 Closure rail.....	337
11.1.4 Rails and sleepers in turnouts.....	337
11.2 Geometry of the turnout.....	337
11.3 High-speed turnouts.....	338
11.3.1 General.....	338
11.3.2 Traditional turnout design method.....	338
11.4 Vehicle dynamic.....	338
11.4.1 Examples of modern high-speed turnouts .....	339

11.5 Notations used for switches and crossings.....	340
11.6 Types of turnouts and crossings.....	340
11.7 Cross-overs .....	341
11.8 Switch calculation .....	344
11.8.1 Relation between curve radius and crossing angle.....	344
11.8.2 Calculation of main dimensions .....	345
11.8.3 Geometrical design of switches and crossings .....	347
11.9 Production, transport and laying of switches .....	347

## 12 TRACK MAINTENANCE AND RENEWAL

12.1 Introduction.....	349
12.2 General maintenance aspects.....	350
12.3 Spot maintenance of track geometry.....	350
12.4 Rail grinding and reprofiling.....	352
12.4.1 Rail grinding machines.....	352
12.4.2 Rail reprofiling machines.....	354
12.5 Correcting weld geometry.....	356
12.5.1 STRAIT principle.....	356
12.5.2 Mobile weld correction.....	357
12.6 Tamping machines.....	357
12.6.1 General considerations.....	357
12.6.2 Tamping principle.....	359
12.6.3 Levelling and lining .....	363
12.6.3.1 Smoothing principle of modern tamping machines.....	363
12.6.4 ALC.....	366
12.6.5 EM-SAT.....	367
12.7 Stone blowing.....	369
12.7.1 General principle.....	369
12.7.2 Measuring philosophy used for the stone blower.....	370
12.7.3 Stone blowing applications.....	371
12.7.4 Results of track geometry measurements.....	373
12.7.5 Stone blowing future.....	373
12.8 Design overlift tamping.....	374
12.9 Ballast profiling and stabilization .....	375
12.10 Mechanised track maintenance train.....	377
12.11 Ballast cleaner.....	377
12.12 Formation rehabilitation machines.....	379
12.13 High temperatures.....	383
12.14 Maintenance of the track structure.....	383
12.15 General observations on track renewal.....	384
12.16 Manual track renewal.....	385
12.17 Mechanical track renewal.....	386
12.17.1 Introduction.....	386
12.17.2 Track possession.....	386
12.17.3 Gantry crane method.....	386
12.17.4 Track section method.....	386
12.17.5 Continuous method.....	388
12.17.6 Track renewal trains.....	392
12.18 Switch renewal.....	393
12.19 Track laying.....	396
12.19.1 General considerations.....	396

12.19.2	Track construction trains.....	396
12.19.3	Platow system.....	397
12.19.4	TGV tracks.....	397
12.20	Deterioration of Track Geometry.....	399
12.20.1	Introduction.....	399
12.20.2	Historical records.....	399
12.20.3	Factors influencing the deterioration of track geometry.....	400
12.20.4	Deterioration rates of geometry .....	402
12.20.5	Effects of tamping.....	403
12.20.6	Effect of weld straightening.....	403
12.20.7	Development of corrugation.....	405
12.20.8	Effect of stone blowing.....	406
12.20.9	Development of lateral track resistance.....	406

## 13 NUMERICAL OPTIMIZATION OF RAILWAY TRACK

13.1	Introduction.....	409
13.2	Elements of structural optimization.....	410
13.2.1	General optimization problem.....	410
13.2.2	Solution process.....	411
13.2.3	Approximation concept.....	411
13.3	MARS method.....	413
13.4	Optimal design of embedded rail structure (ERS).....	415
13.4.1	Introduction.....	415
13.4.2	Requirements for optimum design of ERS.....	416
13.4.3	Optimization problem.....	420
13.4.4	Remarks and conclusions.....	426
13.5	Determination of ballast lateral resistance using optimization technique.....	426
13.5.1	Introduction.....	426
13.5.2	Measuring the lateral resistance of track.....	428
13.5.3	Ballast parameter identification.....	430
13.5.4	Conclusions.....	435
13.6	Identification of dynamic properties of railway track.....	435
13.6.1	Introduction.....	435
13.6.2	Hammer excitation test.....	436
13.6.3	Numerical model.....	437
13.6.4	Track parameter identification.....	438
13.6.5	Numerical results.....	439
13.6.6	Conclusions.....	440

## 14 TESTING AND ACCEPTANCE

14.1	Introduction.....	441
14.2	Component testing and acceptance.....	441
14.2.1	Mechanical properties.....	441
14.2.2	Elasticity properties.....	442
14.2.3	Strength properties.....	446
14.2.4	Stability properties.....	447
14.2.5	Durability and fatigue properties.....	448
14.2.6	Specific component properties.....	449
14.3	Structural testing and acceptance.....	451
14.3.1	Noise and vibration testing of track structures.....	451

14.3.2 Passenger comfort and ride quality .....	453
14.3.3 Dynamic properties of track structures .....	454

## 15 NOISE AND VIBRATION

15.1 Introduction.....	459
15.2 Some definitions.....	459
15.3 Ground vibrations.....	460
15.3.1 Introduction.....	460
15.3.2 Wave propagation in soils.....	462
15.3.3 Human perception.....	464
15.3.4 Measured vibrations.....	466
15.3.5 Vibration reduction.....	468
15.3.6 Measures for ballasted tracks.....	469
15.3.7 Measures for slab tracks.....	469
15.3.8 Measures for tracks in the open.....	470
15.4 Railway noise.....	470

## 16 INSPECTION AND DETECTION SYSTEMS

16.1 Railway Infrastructure Monitoring.....	475
16.2 Tunnel monitoring.....	475
16.3 Bridge monitoring and management.....	476
16.4 Substructure Monitoring .....	477
16.4.1 Substructure condition parameters.....	478
16.4.2 Ground Penetrating Radar.....	479
16.4.3 Track Stiffness Measurement.....	480
16.4.4 Infrared thermographic inspection data .....	484
16.4.5 Laser Induced Fluorescence (LIF) Cone Penetrometer measurement.....	484
16.4.6 Non-invasive moisture monitoring.....	485
16.5 Monitoring and management of switches and crossings.....	486
16.5.1 Introduction.....	486
16.5.2 Switches and crossings monitoring by EURAILSCOUT .....	487
16.5.3 SwitchView.....	488
16.5.4 Condition monitoring and maintenance management of switches.....	489
16.5.5 CEDIAS - Railway Lines Diagnostic System .....	494
16.6 Ultrasonic rail inspection.....	495
16.6.1 Introduction.....	495
16.6.2 The EURAILSCOUT ultrasonic train.....	496
16.6.3 Architecture of the URS .....	497
16.6.4 Probe system.....	498
16.6.5 Sensor electronics .....	500
16.6.6 Incident Processor.....	501
16.6.7 On-line control and data interpretation.....	501
16.6.8 Off-line data analysis and report generation.....	503
16.6.9 NS Ultrasonic inspection program .....	504
16.7 Track Recording Cars.....	506
16.7.1 Introduction.....	506
16.7.2 Track recording systems.....	506
16.7.3 Rail recording systems.....	508
16.7.4 Overhead wire recording.....	509
16.7.5 Video inspection.....	510

16.7.6 Processing and recording the measured data .....	510
16.7.7 Track recording cars.....	511
16.8 Track recording systems.....	513
16.8.1 Introduction.....	513
16.8.2 Some aspects of geometry recording .....	513
16.8.3 Assessment of track quality for maintenance decisions .....	515
16.9 Universal measuring coach EURAILSCOUT .....	515
16.9.1 Introduction.....	515
16.9.2 Track geometry measurement.....	516
16.9.3 Overhead wire measurement.....	517
16.9.4 Rail Profile measurement.....	520
16.9.5 Rail Check System.....	521
16.9.6 Video inspections systems.....	522
16.9.7 Data processing and storing .....	523
16.10 The NS track recording system BMS .....	526
16.10.1 Short-wave recording via axle box accelerations.....	526
16.10.2 Inertial measuring principle.....	526
16.10.3 Dynamic signals.....	527
16.10.4 Quasi-static signals.....	530
16.10.5 Signal combination for determining track parameters.....	531
16.10.6 Signal analysis.....	534
16.11 Vehicle response analysis according to VRA .....	543
16.11.1 Introduction .....	543
16.11.2 Principle of calculation.....	543
16.12 Results from BMS campaigns.....	544
16.12.1 NS distribution functions.....	544
16.12.2 Results from the ORE D 161 Europe Tour.....	544
16.12.3 Track geometry spectra.....	545
16.13 T-16: FRA's High Speed Research Car.....	547
16.13.1 Introduction.....	547
16.13.2 Instrumentation and measurement capabilities .....	547
16.14 Rail Profile Management.....	548
16.15 Rail Defect Management.....	549
16.15.1 Introduction.....	549
16.16 Ballast monitoring and management.....	551
16.17 Hand-held inspection equipment.....	552
16.17.1 Ultrasonic Hand Equipment MT 95.....	552
16.17.2 Hand-held Georadar.....	552
16.17.3 AUTOGRAPH.....	553
16.17.4 MINIPROF .....	554
16.17.5 RAILPROF.....	561
16.18 Pandrol Jackson SYS-10 Rail Flaw Detector.....	565

## 17 HIGH-SPEED TRACKS

17.1 Introduction.....	567
17.1.1 Vehicle reactions.....	567
17.1.2 Track geometry.....	568
17.1.3 Rail geometry and weld geometry .....	570
17.1.4 Track quality standards for 300 km/h.....	570
17.2 The Korean High Speed Railway Project.....	574
17.2.1 Introduction.....	574

17.2.2 Civil Works.....	574
17.2.3 Track Characteristics.....	575
17.2.4 Track Laying.....	575
17.2.5 Track Installation.....	575
17.2.6 Catenary and Systems.....	576
17.3 Dimensions of railway tunnels.....	577
17.3.1 Introduction.....	577
17.3.2 Air resistance in the open field situation .....	577
17.3.3 Tunnel situation.....	578
17.3.4 Basic design criteria for tunnels.....	579
17.3.5 Calculations of external air pressures on the train.....	580
17.3.6 Modeling of the tunnel.....	580
17.3.7 Calculation of air-pressure variations in trains.....	581
17.3.8 Criteria .....	583
17.3.9 Results of calculations for tunnels in the HSL in The Netherlands .....	584
17.4 Maglev Applications.....	584
17.4.1 Introduction.....	584
17.4.2 The Japanese system.....	584
17.4.3 The German Transrapid system .....	586

## 18 TRACK MAINTENANCE MANAGEMENT SYSTEMS

18.1 Introduction.....	591
18.2 Basic data for prediction and planning .....	592
18.3 Track geometry.....	593
18.4 Prediction of geometry deterioration.....	593
18.5 The basics of the analysis principle.....	594
18.6 Monitoring system for wheel defects .....	596
18.7 Rational rail management.....	596
18.8 ECOTRACK.....	596
18.8.1 Introduction.....	596
18.8.2 Overview.....	597
18.8.3 System functions and process.....	598
18.8.4 Features of the ECOTRACK system .....	602

## 19 RAILWAY ASSET MANAGEMENT SYSTEMS

19.1 Railway Asset Management System concept.....	604
19.2 Development of an AMS.....	604
19.3 Railway Assets Locating.....	605
19.3.1 Method using ortho-photo technology.....	605
19.3.2 Method using laser, video and GPS technology.....	606
19.3.3 Video Surveying.....	607
19.3.4 Method using Satellite Imagery.....	610
19.4 Integrating a Railway Asset Management System...	611
19.5 AMS subsystems.....	612

## 20 LIFE CYCLE COST ANALYSIS

20.1 Life Cycle Costing.....	615
20.1.1 Life Cycle Costing principles.....	615
20.2 Track Life Cycle Cost DSS.....	620
20.3 Recent studies.....	625

20.3.1 Track design for a high-speed line.....	625
20.3.2 M&R strategies for tracks and switches.....	627
20.3.3 Conclusion.....	629