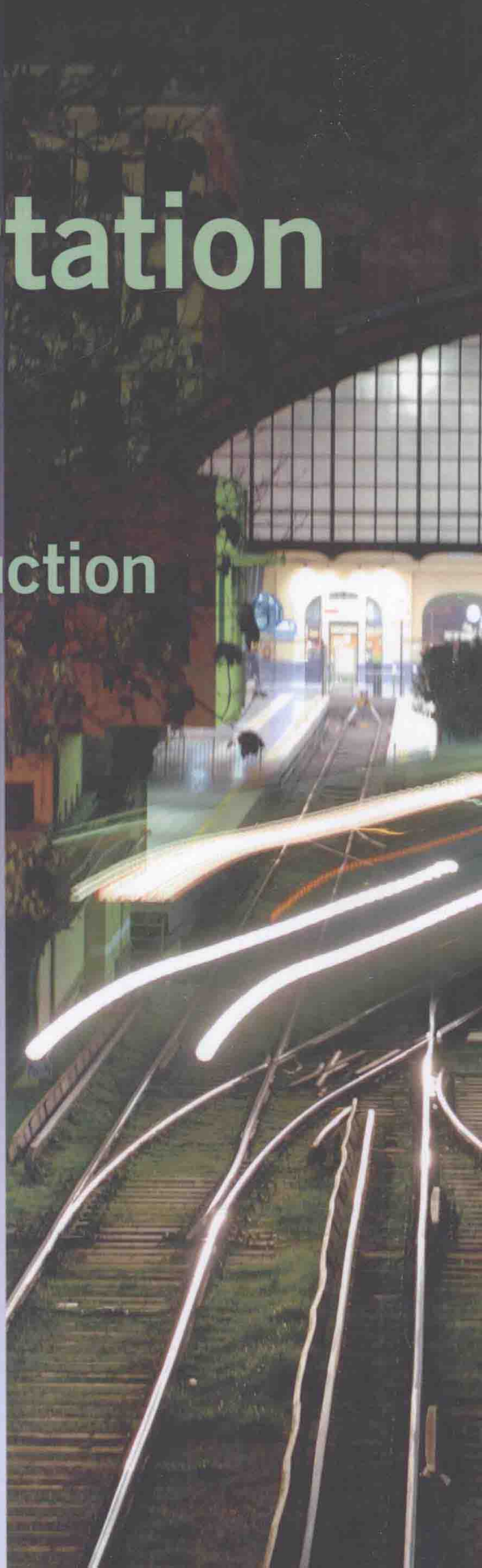
Railway Transportation Systems

Design, Construction and Operation



CHRISTOS N. PYRGIDIS

CRC Press
Taylor & Francis Group
A SPON PRESS BOOK

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Design, Construction and Operation

CHRISTOS N. PYRGIDIS

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CRC Press
Taylor & Francis Group
Boca Raton London New York

CRC Press is an imprint of the
Taylor & Francis Group, an **Informa** business

A SPON PRESS BOOK

CRC Press
Taylor & Francis Group
6000 Broken Sound Parkway NW, Suite 300
Boca Raton, FL 33487-2742

Printed on acid-free paper
Version Date: 20160104

International Standard Book Number-13: 978-1-4822-6215-5 (Hardback)

Library of Congress Cataloging-in-Publication Data

Names: Pyrgidis, Christos N., author.
Title: Railway transportation systems : design, construction and operation / Christos N. Pyrgidis.
Description: Boca Raton : CRC Press, 2016. | "This book presents a comprehensive overview of railway passenger and freight transport systems, from design through to construction and operation. It covers the range of railway systems, from conventional and high-speed inter-urban passenger systems, through suburban and regional and urban, specialist and freight. For each, it provides a definition, a brief overview of its evolution, the main design, construction and operational characteristics, the preconditions for the selection and the steps required to check the feasibility of its implementation." | Includes bibliographical references and index.
Identifiers: LCCN 2015032938 | ISBN 9781482262155 (hardcover : acid-free paper)
Subjects: LCSH: Railroads--Design and construction. | Railroad engineering. | Transportation engineering.
Classification: LCC TF200 .P97 2016 | DDC 625.1--dc23
LC record available at http://lccn.loc.gov/2015032938

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and the CRC Press Web site at
http://www.crcpress.com

Preface

> The development of railway technology reached an early peak and then was found to be in question. During the past decade it has not only managed to rise again, but also be on the cutting edge of technology in many countries.

The term 'railway transportation systems' includes all means of transport whose rolling systems involve at least one iron component (steel wheels on rails or rubber-tired wheels on steel guideway). Because of this, this book examines only transport systems that have this particular characteristic in common.

This book presents a comprehensive overview of passenger and freight railway transport systems, from design through to construction and operation. It covers the range of railway passenger systems, from conventional and high-speed interurban systems through suburban, regional, urban and rail transport systems for steep gradients. Moreover, it thoroughly covers freight railway systems transporting conventional loads, heavy loads and dangerous goods. For each system it provides a definition, a brief overview of its evolution and examples of good practice, the main design, construction and operational characteristics, the preconditions for its selection and the steps required to verify the feasibility of its implementation.

The book provides a general overview of issues related to safety, interfaces with the environment, cutting-edge technologies and finally the techniques that govern the stability and guidance of railway vehicles on track.

It incorporates the author's 25 years of involvement in teaching, research and experience in railway engineering.

Until recently, knowledge of railway technology was shared only among railway organisations. Many of the organisations' executives changed job positions in order to broaden their vision and knowledge. In recent years, an increasing number of people have become involved in the field of rail transport worldwide (engineers, consultants, manufacturers, transport companies, etc.).

This book provides additional information for those interested in learning about railway transportation systems. It can be used as a decision-making tool for both designers and operators of railway systems. In addition, it attempts to educate young railway engineers to enable them to deal with rail issues that may be assigned to them during the course of their careers.

All the data recorded and analysed in this book relate to the end of year 2014. The raw data were obtained per country, per city and per line, from various available sources and were cross-checked.

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Acknowledgements

I thank everyone who has helped me complete this work.

Specifically, I wish to thank:

- My colleagues: Constantina Anastasiadou, Nikolaos Asmeniadis, Alexandros Panagiotopoulos, Rafael Katkadigkas, civil engineers, Dr. Evangelos Christogiannis, Dr. Alexandros Deloukas, Dr. Nikolaos Demiridis, Dr. Nikolaos Gavanas, Dr. Anastasios Lambropoulos, Dr. Georgios Leoutsakos, Professor Antonios Stathopoulos, Professor François Lacote. All of them agreed with pleasure to read through chapters of my book and provided useful comments.
- Ifigeneia Balampekou, transport engineer, for assisting with the translation and text editing.
- Artemis Klonos, professional photographer, who provided most of the pictures in this book.
- Ntia Regka, architect, for editing the figures.
- My dear friend Alexandros Kolokotronis, who helped in the selection and design of the book's cover.
- All my graduate and postgraduate students, who contributed in different ways to the final result.

I acknowledge all organisations, institutions, private companies and individuals for providing and permitting me to use tables, figures and photographs. Specifically, I thank: edilon)(sedra, Siemens, SNCF, SNCF Médiathèque, Posco ICT Co. Ltd, DCC Doppelmayr Cable Car, Innsbrucker Nordkettenbahnen Betriebs GmbH, Voestalpine Nortrak Ltd., Talgo, Vossloh Fastening Systems GmbH, Mermecgroup, BONATRANS GROUP a.s., Peer plus, Struktonrail bv, ANSALDO STS, Bombardier Transport, Alstom Transportation, UIC, ABB, Railway Gazette International, RATP, UITP, LEA+ELLIOTT Inc., Eyrolles Editions, MRT-Productions, Transportation Safety Board of Canada, CERTU, LEITNER AG/SpA, U.S. Department of Transportation Federal Highway Administration, Urbanaut, Hitachi Ltd, Professor C. Hass-Klau, Ev. Krussev, K. Pedersen, A. Takahashi, Br. Finn, Dr. K. Giannakos, L. Zlateva, Professor S. Iwnicki, Professor V. Profillidis, Associate Professor K. Vogiatzis, Professor Coenraad Esveld, D. Oikonomidis, Ben Betgen, Harald Loy and S. Dale.

Last but not least, I thank Taylor & Francis Group for editing and publishing this book and for the excellent collaboration throughout the process.

Author

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Symbols and Abbreviations

A	track category in accordance with UIC (based on the permitted axle load)
A_r	rail cross section
A_p	bogies pivot centre
A_w	parameter depending on the characteristics of the rolling stock and representing the rolling resistance
AC	alternative current
AFC	automatic fare collection system
AGT	automated guideway transit system
APMs	automated people movers
APS	Alimentation Par le Sol – Ground power supply system for tramways
APT	advanced passenger train
ATO	automatic train operation
ATP	automatic train protection system
ATS	automatic train supervision system
a_b	parameter that depends on the classification of the track in the UIC classes
a_d	lateral distance of the noise barrier from the track centre
2a	bogie wheelbase
B	track category in accordance with UIC (based on the permitted axle load)
B_r	rail's weight per metre
B_t	vehicle weight
B_{tr}	train's weight
B_{ty}, B_{tz}	lateral and vertical components of the vehicle weight–motion in curves
B_w	parameter depending on the characteristics of the rolling stock and representing the mechanical resistances
BODu	biochemical oxygen demand
BTU	British Thermal Unit
b_b	parameter depending on the sleepers' length and material
b_{cp}	width of a centre (island) platform
b_{em}	width needed for the installation of electrification masts
b_{lp}	width of a side platform
b_{sw}	width of separator (tramway corridors)
b1, b2	width of two intersected roads (1 and 2) (tramway network)
C	track category in accordance with UIC (based on the permitted axle load)

C_{hmin}	constructional height in the middle of the catenary opening
C_o, C'_o	track maintenance cost
C_{thr}	centre throw
C_v	transport capacity of a passenger train or vehicle
C_{vph}	transport capacity of a passenger train or vehicle in peak hours
C_w	parameter depending on the characteristics of the rolling stock and representing aerodynamic resistance
$\bar{C}_x, \bar{C}_y, \bar{C}_z$	damping coefficients of the secondary suspension dampers in the three directions, respectively
C_ρ	damping torsional torque
C_φ	damping coefficient
CBTC	communications-based train control systems
CCTV	closed-circuit television
CIM	Convention Internationale Marchandises par Chemin de Fer (contract of international carriage of goods by rail)
COTIF	Convention Transports Internationaux Ferroviaires (convention concerning international carriage by rail)
CWR	continuous welded rails
c_b	parameter that depends on the volume of the required track maintenance work
c_{ij}	coefficients of Kalker
c_{11}	longitudinal creep coefficient of Kalker
c_{22}	transversal creep coefficient of Kalker
c_{23}, c_{33}	spin coefficients of Kalker
D	track category in accordance with UIC (based on the permitted axle load)
D_o	minimum wheel diameter of trains running along the line
DC	direct current
DMU	diesel multiple unit
DRNT	design rail neutral temperature
DTO	driverless train operation
DVT	driving van trailer
d_b	parameter that depends on the maximum axle load
d_o	vibration displacement
d'_o	reference vibration displacement
2d	lateral distances between springs and dampers of the primary suspension
$2d_a$	back-to-back wheel distance (inside gauge)
E	steel elasticity modulus
E_b	parameter that depends on the quality category of the soil and the bearing capacity of the substructure
E_c	track cant excess
E_{cmax}	maximum track cant excess
E_d	total ground plan area of a depot
E_{thr}	end throw

EMU	electrical multiple unit
ERA	European Railway Agency
ESS	energy storage systems
EU	European Union
EXCA	EXceeded capacity
e_b	ballast thickness
e_{bt}	total thickness of ballast and sub-ballast layers
e_{sb}	sub-ballast thickness
2e	track gauge
$2e_a$	outer flange edge-to-edge distance (flange gauge)
$2e_o$	theoretical distance between the running surfaces of the right and the left wheels when centered ≈ distance between the vertical axis of symmetry of the two rails
F	guidance effort exerted from the wheel to the rail
F_{cf}	centrifugal force
F_{cfy}, F_{cfz}	lateral and vertical components of the vehicle's centrifugal force – motion in curves
F_{ij}	guidance forces exerted from the four wheels of a 2-axle bogie to the rails (i = 1,2 front and rear wheelset, respectively; j = 1,2 left and right wheel, respectively, in the direction of movement)
F_{nc}	residual centrifugal force
F_t	traction effort developed on the driving wheel treads
F_{tr}	traction effort acting on the axles
f	frequency of oscillation
f_b	parameter that depends on the track design speed and the bearing capacity of the substructure
f_d	wheel flange width
G	geometrical centre of a railway wheelset
G′	centre of gravity of the car body
GoA	grade of automation (metro systems)
GPS	global positioning system
GRT	group rapid transit
g	gravity acceleration
g_{dv}	dynamic gauge width of tram vehicle
g_i	maximum track twist
g_{imax}	highest permitted value for track twist
H_R	lateral track resistance
H_w	cross wind force
h	height clearance under civil engineering structure
h_f	wheel flange height
h_{fc}	height of the catenary contact wire
h_{KB}	distance between the vehicle's centre of gravity and the rail rolling surface
h_o	track lifting after maintenance work
I	track cant deficiency

I_{max}	maximum track cant deficiency
I_l	isolation distance of wire-grounded structures
IRR	internal rate of return
i	track longitudinal gradient (or slope)
i_{max}	maximum track longitudinal gradient (or slope)
i_{min}	minimum track longitudinal gradient (or slope)
j = 1, 2	indicator relative to the two wheels of the same wheelset
K	factor of decrease of the aerodynamic load exerted to noise barriers
K′	factor of increase of the aerodynamic load exerted to noise barriers
K_b	angular stiffness of the link between the two wheelsets of the bogie (bogies with self-steering wheelsets)
K_{bt}	total longitudinal stiffness of the primary suspension system (bogies with self-steering wheelsets)
K_{dyn}	vertical dynamic stiffness
K_m	coefficient with values varying between 1.15 and 1.45
K_o	bogie–yaw dampers stiffness
K_{op}	operating cost
K_{st}	total lateral stiffness of the primary suspension (bogies with self-steering wheelsets)
K_{stat}	vertical static stiffness
K_t	coefficient that depends on the rolling conditions of the power vehicle axles on the track
K_x	longitudinal stiffness of the primary suspension (springs)
K_y	lateral stiffness of the primary suspension (springs)
K_z	vertical stiffness of the secondary suspension (springs)
K_ς	lateral stiffness of the link between the two wheelsets of the bogie (bogies with self-steering wheelsets)
K_1	parameter depending on the shape of the 'nose' and the 'tail' of the train
K_2	parameter depending on the lateral external surface of a train
k	vertical track stiffness
L_{den}	day–evening–night equivalent noise level
L_{dn}	day–night equivalent noise level
$L_{eq,T}$	equivalent energy noise level
L_h	length over headstock
L_{kmin}	minimum allowed length for a transition curve
L_{max}	maximum noise level
L_{st}	distance between two successive stops
L_T	civil engineering structure width
L_{tr}	train's length
L_w	oscillation wave length (hunting of railway wheelset)
LC	locomotive
LCL	less-than-carload
LED	light emitting diode
LIM	linear induction motors

LRC	laser railhead cleaner
LRTs	light rail transport systems
LRV	light rail vehicles
LTL	less-than-truckload
l_A	expansion zone length of rail
l_o	initial rail length
l_T	civil engineering structure length
M	spin moment on wheels
M′	mass of one bogie
$\bar{M}$	car body mass
M_t	total mass of the vehicle
M_1, M_2	spin moment in the left and right wheels, respectively, in the direction of movement of a railway wheelset
MC	motor car
MU	multiple unit
m	mass of one railway wheelset (axle + wheels + axle-boxes)
N	temperature force
N′	reaction force in the wheel–rail contact surface
N_{ac}	acceleration force
N_{br}	braking force
NATM	New Austrian Tunneling Method
NPV	net present value
n_b	total number of bogies of a train formation
n_p	coefficient of the probability augmentation of the mean square value of standard deviations of vertical dynamic forces of a vehicle
n_s	number of intermediate stations/stops
OCS	overhead power supply (catenary) system
P_d	total number of passengers expected to be transported along a specific connection (passengers/hour/direction or daily-potential transport volume)
P'_d	passenger transport capacity of the system (passengers/hour/direction)
P_{dph}	total number of passengers expected to be transported along a specific route during the peak hours
P_{dyn}	transversal force due to vehicle oscillations
P_f	fishplate force
P_t	net or useful power of motors
P_{4w}	power consumed at the level of the four wheels of the bogie
PPV	peak particle velocity
PR	single railcar
PRT	personal rapid transit
PSD	platform screen doors
PSE	Paris–Sud–Est
PT	public means of transport
p	the perimeter that encloses the rolling stock laterally, up to rail level (rolling stock outline)

p_o	mean noise pressure
p'_o	the relative mean reference pressure
ppl	population of a city
Q	axle load
Q_d	design vertical wheel load
Q_{Do}	maximum passing axle load (wheels of diameter D_o)
Q_{dyn}	dynamic vertical wheel load
Q_{dyn1}	dynamic vertical wheel load due to the vehicle's sprung masses
Q_{dyn2}	dynamic vertical wheel load due to the vehicle's semi-sprung masses
Q_{dyn3}	dynamic vertical wheel load due to the vehicle's unsprung masses
Q_{dyn4}	dynamic vertical wheel load due to the oscillations of the elastic parts of the rail-sleeper fixing system
Q_H	quasi-static vertical wheel load
Q_{max}	maximum axle load or design vertical axle load of a railway infrastructure
Q_{nc}	vertical wheel load due to residual centrifugal force
Q_o	wheel load (=Q/2)
Q_t	total static vertical load of wheels (j = 1,2)
Q_w	vertical wheel load due to cross winds
Q_1, Q_2	total static vertical load of the left and right wheels, in the direction of movement of a railway axle
q	uniform load applied to noise barriers
q_o	vertical distance between the geometrical centre of the lateral surface of the car body and the rail rolling surface
q_r	flange cross-dimension (the horizontal distance between the intersection point of the joint geometric level with the flange face and the intersection point of a reference line at a distance of 2 mm from the flange tip with the flange face)
R	curvature radius of the wheel tread
R′	radius of curvature of the rolling surface of the rail head
R_c	radius of curvature in the horizontal alignment
R_{cmin}	minimum radius of curvature in the horizontal alignment
R_{co}	horizontal alignment radius as it derives from simulation models
R_s	sound-insulating capacity index of the construction material of noise barriers
R_v	radius of curvature in the vertical alignment
R_{vmin}	minimum radius of curvature in the vertical alignment
RID	Regulation International de Transport des Produits Dangereux par Chemin de fer (international carriage of dangerous goods by rail)
RLC	railway level crossing
RNT	rail neutral temperature
ROLA	ROllende LAndstraβe – rolling road or highway transport
r_o	rolling radius of the wheel in the central equilibrium position
r_1, r_2	rolling radius of the left and the right wheels in the direction of movement of a railway wheelset in case of lateral displacement from its central equilibrium position

$2r_o$	wheel diameter
S	route, link, or connection length
S_A, S_B, S_C, S_D, S_E	tramway corridor length for corridor categories A, B, C, D, E, respectively
S_c	affected cross section surface of the train
S_{max}	maximum route or link or connection length
S_{min}	minimum route or link or connection length
S_p	total gravitational force, restoration force or gravitational stiffness
S_{p1}, S_{p2}	gravitational forces exerted on the left and the right wheels when the wheelset is displaced from its central equilibrium position
S_u	useful cross section area of the tunnel
S_v, S_m	coefficients with values depending on the speed of passenger (with the highest speed) and freight (with the lowest speed) trains, respectively, running on the track
SEL	sound exposure level
SPD	suspended partical devices
SPL	sound pression level
STO	semi-automatic train operation
SNCF	Société Nationale des Chemin de Fer Français (national company of French railways)
SW	loading model in railway bridges (heavy loads)
SWL	single wagon load services
T	lateral creep force applied on the wheel
T_f	total daily traffic load
T_{fr}	friction forces between rails and sleepers and between sleepers and ballast
T_g	daily traffic load of freight trains
T_{ij}	lateral creep forces exerted to the four wheels of a 2-axle bogie (i = 1,2 front and rear wheelset, respectively, j = 1,2 left and right wheels, respectively, in the direction of movement)
T_m	average daily traffic load of trailer freight wagons
T_p	daily traffic load of passenger trains
T_{tm}	average daily traffic load of freight trains' power vehicles
T_{tv}	average daily traffic load of passenger trains' locomotives
T_V	average daily traffic load of trailer passenger cars
T_1, T_2	lateral creep forces exerted to left and right wheels (in the direction of movement) of a railway wheelset
TBM	tunnel boring machine
TC	trailer vehicle (car) of a train
TC′	trailer vehicle (car) of a railcar
TGV	Train Grande Vitesse (high-speed train [French technology])
TGV-A	TGV Atlantique (TGV Atlantic)
TL	train load services
TOFC	trailer of flat cars
TSIs	technical specifications interoperability

TT	single tramway track
TTROW	total tramway infrastructure right-of-way
TTROWC	total tramway infrastructure right-of-way in curves
TTROWS	total tramway infrastructure right-of-way in straight path
TTROWST	total tramway infrastructure right-of-way in stops' areas
t	travel time (run time)
t′	year of change of the corridor's operating frame
t_{fin}	year of the end of the economic life of a project
$t_{re} - t_{in}$	actual (recorded) temperature minus initial temperature of the rail
t_s	dwell time at stations/stops
t_{ts}	dwell time (waiting time) of trains at the two terminal stations of a route
U	track (normal) cant
U_{max}	maximum (normal) track cant
U_{th}	theoretical track cant
UAE	United Arab Emirates
UIC	Union International des Chemins de Fer (international union of railways)
UIC1, 2, 3, 4, 5, 6	track categorisation in accordance with UIC (based on the total daily traffic load)
USM	unsprung masses of the vehicle (one wheelset)
UTO	unattended train operation
UTS	ultimate tensile strength
V	train or vehicle or wheelset running or transit or forward speed
V_{amaxtr}	average permissible track speed
V_{ar}	average running speed
V_c	commercial speed
V_{CA}, V_{CB}, V_{CC}, V_{CD}, V_{CE}	commercial speed of tramways running on corridor categories A, B, C, D, E, respectively
V_{cmax}	maximum commercial speed
V_{cr}	vehicle critical speed
V_d	track design speed
V_{dmax}	maximum track design speed
V_{fr}	maximum speed for freight trains
V_{max}	train maximum running speed
V_{maxtr}	permissible track speed
V_{min}	running speed of the slowest trains circulating along a line – minimum running speed
V_{op}	train operating speed
V_p	train passage speed
V_{pas}	maximum speed of passenger trains
V_{pmax}	maximum train passage speed
V_{rs}	rolling stock design speed
V_t	train instant speed

V_1, V_2	relative velocities of the left and right wheels (in the direction of movement) of a railway wheelset
VAL	vibration acceleration level
VPF/VPC	value of preventing a fatality/casualty
VPI	value of preventing an injury
VVL	vibration velocity level
v_o	vibration velocity
v_o'	reference level of vibration velocity
W	total train resistance
W_{ac}	acceleration resistance
W_B	basic resistance
W_i	track gradient resistance
W_m	movement resistance
W_{Rc}	track curve resistance (drag)
W_{tr}	total track resistance
W_α	air resistance or aerodynamic resistance or aerodynamic drag
WILD	wheel impact load detector
X	longitudinal creep force applied on the wheel
X_{ij}	longitudinal creep forces exerted to the four wheels of a 2-axle bogie (i = 1,2 front and rear wheelset, respectively; j = 1,2 left and right wheels, respectively, in the direction of movement)
X_1, X_2	longitudinal creep forces exerted to left and right wheels (in the direction of movement) of a railway wheelset
x	longitudinal displacement of the wheelset
x′	derivative of the longitudinal displacement x of a railway wheelset
Y_1	total transversal force exerted on the rail via the wheel flange of the derailing wheel
y	lateral displacements of the wheelset in relation to its central equilibrium position
y_i	lateral displacements of the two wheelsets of a bogie (i = 1,2 front and rear wheelset, respectively)
y_o	lateral displacement of the wheelset in case of its radial positioning in curves (wheelset lateral offset)
y_w	oscillation wave amplitude (hunting of railway wheelset)
y′	derivative of the lateral displacement y of a railway wheelset
y''_{max}	maximum lateral acceleration of a railway wheelset
yy	derailment force axis
σ	flange way clearance
$\sigma(Q_{dyn1}, Q_{dyn2})$	typical deviation of the dynamic vertical forces of the sprung and semi-sprung masses of the vehicle
$\sigma(Q_{dyn3})$	typical deviation of the dynamic vertical forces of the un-sprung masses of the vehicle
ω	angular velocity of the two wheels of a conventional wheelset
ω_1, ω_2	angular velocities of the left and the right wheels (in the direction of movement) of a railway axle equipped with independently rotating wheels

γ_o	inclination of the tangent plane at the contact point between rail and wheel when the wheelset is in central position
γ_1, γ_2	angles formed by the horizontal plane, and the tangent planes at the contact points I_1 and I_2, respectively, when the railway wheelset is displaced from its central equilibrium position
γ_{nc}	lateral residual acceleration
γ_{ncmax}	maximum permitted lateral residual acceleration
γ_e	equivalent (or effective) conicity of the wheel
α	yaw angle of the wheelset
α'	derivative of the yaw angle α of a railway wheelset
α_{at}	angle of attack
α_{br}	coefficient of the vertical static loads of railway bridges
α_o	vibration acceleration
α'_o	reference level of vibration acceleration
α_s	sound-absorption coefficient
α_t	steel thermal expansion coefficient
$2\alpha_f$	angle of vertical displacement of the joint (sum of the angles that are formed by the two rails and the horizon)(rad)
ΣY	total transversal force
ΣQ	overall train weight
Π	adhesion force
π	constant equal to 3.14
μ	wheel–rail friction coefficient (adhesion coefficient, Coulomb coefficient)
Δ	distance between track centers (double track)
Δ_t	temperature change
$\Delta I_{max}/\Delta t$	maximum rate of change of cant deficiency
Δl	variation of the length of the rail
ΔP_{max}	maximum permissible change in pressure generated inside the tunnels
δ_p	angle of cant
φ	angle of rotation of the wheels and the axle
φ'	derivative of the angle of rotation φ of the wheels and the axle
φ_{bri}	dynamic coefficient for the loading of railway bridges (i = 2 or 3)
φ_o	road intersection angle
φ_t	tilting angle of car body
φ_1, φ_2	angles of rotation of two wheels of the same wheelset (axle with independently rotating wheels)
β	wheel–rail contact flange angle
β	coefficient that is empirically determined depending on the type of the superstructure wear
ν	exponent with values between 3 and 4
λ	coefficient

Contents