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DETERIORATION OF RAILWAY TRACK DUE TO DYNAMIC VEHICLE LOADING AND SPATIALLY VARYING TRACK STIFFNESS

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THESIS SUMMARY

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Robert Desmond FRÖHLING

Supervisor:	Professor W Ebersöhn
Co-Supervisor:	Doctor H Scheffel
Department:	Civil Engineering
University:	University of Pretoria
Degree:	Philosophiae Doctor (Engineering)

In this thesis a Dynamic and a Static Track Deterioration Prediction Model are developed to predict track deterioration due to dynamic vehicle loading and nonlinear spatially varying track stiffness. The research also contributes to a better understanding of the relationship between spatially varying track stiffness and track deterioration.

Preceding the development of the Track Deterioration Prediction Models, experimental work was done to simultaneously measure the dynamic behaviour of a rail vehicle and the corresponding response of the track. On-track measurements were made as a function of vehicle speed, axle load, track condition, and accumulating traffic. In this process a new technique to measure the dynamic track stiffness was developed.

Track Deterioration Prediction Models were developed systematically to gain a better understanding of the relative influence of vehicle and track parameters. The dynamic prediction model consists of two elements, an eleven degree-of-freedom dynamic vehicle/track model and a modified track settlement equation, while the static prediction model is based only on the modified settlement equation. The modified settlement equation is based on measurable parameters of the track superstructure, substructure layer properties, the spatial variation of the track stiffness, and the prevailing wheel loading. Using the dynamic interaction between the vehicle and the track, dynamic track loading and differential track settlement are predicted. After validating the model against test results, two applications of the model are given. In the first application void forming is predicted and in the second application the length of a tamping cycle is predicted.

Research presented in this thesis shows that the spatial variation of the track stiffness contributes significantly to track deterioration, both in terms of differential track settlement and increased dynamic vehicle loading. It is thus recommended that track maintenance procedures should be used to reduce the variation of the spatial track stiffness.

Keywords: Track deterioration, track stiffness, track settlement, prediction model, dynamic interaction.

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SAMEVATTING VAN PROEFSKRIF

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In hierdie proefskrif is 'n Dinamiese en 'n Statiese Spoorbaanagteruitgang-voorspellingsmodel ontwikkel om spoorbaanagteruitgang te voorspel as gevolg van dinamiese voertuigbeladings en nie-liniêre afstandgebaseerde variasies in spoorbaanstyfheid. Die navorsing dra ook by tot 'n beter begrip van die verwandskap tussen afstandgebaseerde variasies in spoorbaanstyfhede en spoorbaanagteruitgang.

Voordat met die ontwikkeling van die spoorbaanagteruitgangvoorspellingsmodelle begin is, is eksperimentele werk gedoen om gelyktydig die dinamiese gedrag van die spoorvoertuig en die gepaardgaande reaksie van die spoorbaan te meet. Hierdie meetings is gedoen as 'n funksie van voertuigspoed, asbelasting, spoorbaantoestand, en toenemende verkeer. In dié proses is 'n nuwe tegniek ontwikkel om die dinamiese spoorbaanstyfheid te meet.

Na voltooiing van die toetse is die spoorbaanagteruitgangvoorspellingsmodelle ontwikkel. Die ontwikkeling is stapsgewys gedoen om 'n beter begrip van die relatiewe invloed van voertuig- en spoorbaanparameters te ondersoek. Die dinamiese voorspellingsmodel bestaan uit twee komponente, 'n elf vryheidsgraad dinamiese voertuig/spoorbaanmodel en 'n gemodifiseerde vergelyking vir spoorbaanversakking, terwyl die statiese model slegs van die gemodifiseerde vergelyking vir spoorbaanversakking gebruik maak. Die gemodifiseerde vergelyking vir spoorbaanversakking is gebaseer op meetbare parameters van die spoorbaanstruktuur, die eienskappe van die substruktuur, die afstandsgebaseerde variasie van die spoorbaanstyfheid, en die heersende wielbelasting. Deur gebruik te maak van die interaksie tussen die voertuig en die spoorbaan, word die dinamiese wielbelasting en die variërende spoorbaanversakking voorspel. Nadat die modelle geverifeer is teen toetsresultate, is twee toepassings van die model gegee. In die eerste toepassing word die vorming van 'n slapte in the spoorbaan voorspel en in die tweede toepassing word die lengte van 'n onderstopsiklus voorspel.

Die navorsing wat gedoen is toon aan dat die afstandgebaseerde variasie in die styfheid van die spoorbaan beslis bydra tot spoorbaanagteruitgang in terme van variërende spoorbaanversakking en toenemende dinamiese wielbelasting. Meer effektiewe spoorbaanonderhoud behoort dus die afstandsgebaseerde variasie van die spoorbaanstyfheid te verminder.

Sleutelwoorde: Spoorbaanagteruitgang, spoorbaanstyfheid, spoorbaanversakking, voorspellingsmodel, dinamiese interaksie.

ABSTRACT

Title:	Deterioration of railway track due to dynamic vehicle loading and spatially varying track stiffness
Author:	R D Fröhling
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LIST OF SYMBOLS

$B_{e'}$	:	Effective resolution bandwidth
b	:	Half distance between the secondary suspension on one bogie
b_{cc}	:	Half bogie centre distance
C	:	Ballast material constant
C_f	:	Foundation modulus
C_{slope}	:	Friction wedge stick slope
d_i	:	Difference between the elevation at the point of measurement and the mean filtered elevation
E	:	Young's modulus
F_{ff}	:	Wedge friction force
I	:	Rail moment of inertia about its horizontal axis
I_1	:	Vehicle body moment of inertia in roll
I_2	:	Bogie frame moment of inertia in roll
I_p	:	Vehicle body moment of inertia in pitch
I_w	:	Wheelset moment of inertia in roll
K_1	:	Settlement constant
K_2	:	Settlement constant
K_3	:	Track stiffness correction factor
k	:	General vertical track stiffness
k_1	:	Vertical stiffness of secondary suspension
k_2	:	Effective linearised vertical track stiffness
k_{2i}	:	Calculated track stiffness at a particular sleeper
k_{2mi}	:	Measured track stiffness at a particular sleeper
k_{2BL}	:	Vertical track stiffness under the left wheel of the trailing wheelset
k_{2BR}	:	Vertical track stiffness under the right wheel of the trailing wheelset
k_{2FL}	:	Vertical track stiffness under the left wheel of the leading wheelset

k_{2FR} : Vertical track stiffness under the right wheel of the leading wheelset

k_p : Vertical stiffness of primary suspension

k_{ss} : Stiffness of one stabiliser spring

L_c : Characteristic length

l : Half distance between the wheel and rail contact points

m_1 : Mass of vehicle body

m_2 : Mass of wheel or bogie frame

m_w : Mass of wheelset

N : Number of load cycles

n : Number of measurement in the length of the track under consideration

n_p : Ballast porosity

P : Concentrated force applied to the rail

P_{dyn} : Prevailing dynamic vertical wheel load

P_{ref} : Static reference vertical wheel load

P_s : Static wheel load

q : Vertical force in rail foundation per unit length

R : Track roughness

T : Total measuring time

u : Track modulus

V : Vehicle speed

x : Distance in direction of vehicle travel

x_{ss} : Static deflection of the stabiliser spring from its free height

y : Local deflection of the track support

y_0 : Vertical track profile variation

y_1 : Vertical displacement of vehicle body

y_2 : Vertical displacement of wheel or wheelset

y_B : Vertical displacement of trailing bogie frame

y_F : Vertical displacement of leading bogie frame

y_s : Static track deflection

y_{BL} : Vertical track profile variation under the left wheel of the trailing wheelset

y_{BR} : Vertical track profile variation under the right wheel of the trailing wheelset

y_{FL} : Vertical track profile variation under the left wheel of the leading wheelset

y_{FR} : Vertical track profile variation under the right wheel of the leading wheelset

z_B : Vertical displacement of trailing wheelsets

z_F : Vertical displacement of leading wheelsets

ΔP : Dynamic wheel load component

α : Pitching angle of vehicle body

α_w : Angle of friction wedge

δ : Ratio of dynamic wheel load component to static wheel load

ϵ_N : Permanent axial strain in ballast after N cycles

ϵ_1 : Permanent axial strain in ballast caused by the first load cycle

ϵ_r : Normalized standard error

θ : Rolling angle of vehicle body

μ : Coefficient of friction

ρ_1 : Vertical damping of secondary suspension

ρ_{1BL} : Vertical damping of the secondary suspension on the left side of the trailing bogie

ρ_{1BR} : Vertical damping of the secondary suspension on the right side of the trailing bogie

ρ_{1FL} : Vertical damping of the secondary suspension on the left side of the leading bogie

ρ_{1FR} : Vertical damping of the secondary suspension on the right side of the leading bogie

ρ_2 : Vertical track damping

ρ_P : Vertical damping of primary suspension

σ : Local compressive stress on the track support

σ_1 : Major principle stress

σ_3 : Minor principle stress

ϕ_B : Rolling angle of trailing bogie frame

ϕ_F : Rolling angle of leading bogie frame

ω_B : Rolling angle of trailing wheelsets

ω_F : Rolling angle of leading wheelsets