

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

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THESIS SUMMARY

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

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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.



SAMEVATTING VAN PROEFSKRIF

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In hierdie proefskrif is 'n Dinamiese en 'n Statiese Spoorbaanagteruitgangvoorspellingsmodel 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 afstandgebaseerde 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 geverifieer 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 afstandgebaseerde 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

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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_{IBL} : Vertical damping of the secondary suspension on the left side of the trailing bogie
- ρ_{IBR} : Vertical damping of the secondary suspension on the right side of the trailing bogie
- ρ_{IFL} : Vertical damping of the secondary suspension on the left side of the leading bogie
- ρ_{IFR} : 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