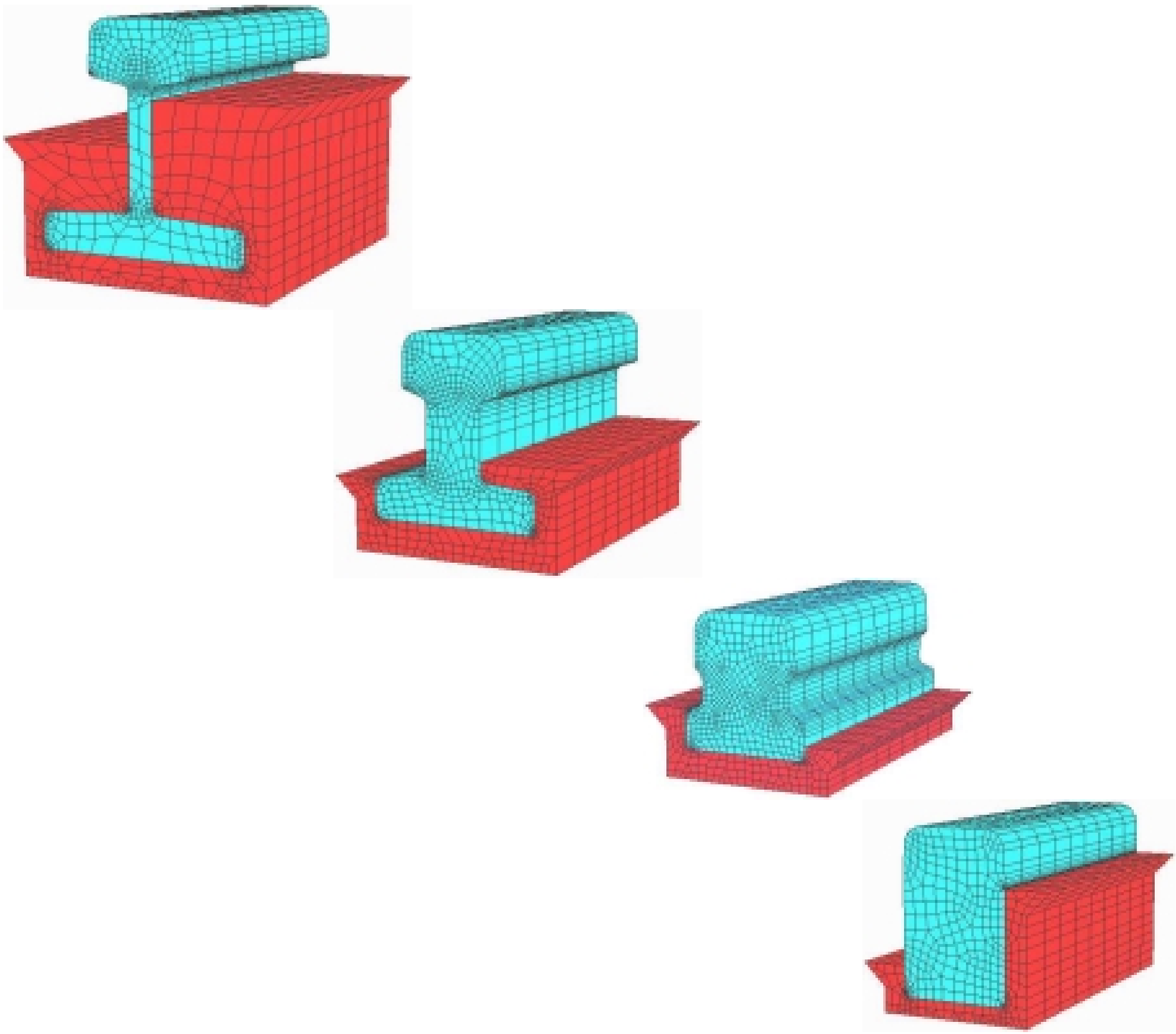
Delft University of Technology

Sub Faculty of Civil Engineering
Section of Road and Railway Engineering
Stevin IV building
Stevinweg 1, Delft, the Netherlands
Tel: +31 15 278 5066
Fax +31 15 278 3443
E-mail: c.esveld@citg.tudelft.nl
Website: vbk.ct.tudelft.nl

Prof.dr.ir. C. Esveld
Professor in Railway Engineering

Annual Report

Chair for Railway Engineering



Report period 1 September 1998 - 31 August 1999

file: Q:\railbouw\algemeen\jaarverslag\Annual Report RE 9899.doc

CONTENTS

Front page: picture series of rail profile transformation during optimisation process.

1 GENERAL

1.1 Scope

The academic year 1 September 1998 – 31 August 1999 was dominated by an intensive research effort emanating from the High Speed Line South project in the Netherlands. Research programmes were carried out in the field of reviewing generic specifications, dynamic modelling and testing components.

In spite of the excellent job prospects, very few students opt for Railway Engineering as a graduation possibility. The apparent obscure position and possibilities of Railway Engineering in the current curriculum should therefore be highlighted further to inform prospective students more effectively. In co-operation with other appropriate engineering groups in the subfaculty of Civil Engineering a number of new rail track related graduation subjects were formulated and distributed. Also third-year students will be presented with a new computer aided instruction program about rail structures that may also arise student interest in the specialisation Railway Engineering.

Staff members were participating in a number of research committees dealing with theoretical and experimental aspects of existing and new rail track structures. One of the staff members, Dr.ir. V.L. Markine, obtained his doctorate with a thesis called 'Optimisation of the dynamic behaviour of mechanical systems'.
A new staff member, Stanislav Jovanovic Msc, joined the Railway Engineering group as per 1 March 1999 on a 50% basis. He will cover the field of management systems. Nevertheless, a few staff vacancies are still open.

1.2 Personnel Railway Engineering group

The following list shows the personnel active in railway engineering duties per 1 September 1999:

NAME	PHONE NUMBER	E-MAIL
Chair for railway engineering		
Prof.dr.ir. C. Esveld	+31 15 278 7122	c.esveld@citg.tudelft.nl
Secretariat (Section Road and Railroad Engineering)		
Mrs. J. Barnhoorn	+31 15 278 5066	j.barnhoorn@citg.tudelft.nl
Mrs. I. Weijgertze	+31 15 278 5066	i.weijgertze@citg.tudelft.nl
Fax	+31 15 278 3443	
Staff		
Dr.ir. A.W.M. Kok	+31 15 278 3206	a.kok@citg.tudelft.nl
Dr.ir. V.L. Markine	+31 15 278 3206	v.l.markine@citg.tudelft.nl
Ir. P.B.L. Wiggenraad	+31 15 278 4916	p.wiggenraad@citg.tudelft.nl
Ir. J. van 't Zand	+31 15 278 2304	j.zand@citg.tudelft.nl
Ph.D.		
Ir. A.P. de Man	+31 15 278 4011	a.deman@citg.tudelft.nl
Ir. S. Rasmussen	+31 15 278 2763	s.rasmussen@citg.tudelft.nl
Ir. A.S.J. Suiker	+31 15 278 2731	a.suiker@citg.tudelft.nl
Ir. J. Zwarthoed (per 1/12)	+31 15 278 4011	j.zwarthoed@citg.tudelft.nl
S. Jovanovic, M.Sc	+31 15 278 2325	s.jovanovic@citg.tudelft.nl

Furthermore, the following Laboratory members are involved in carrying out special tasks for Railway Engineering:

NAME	PHONE NUMBER	E-MAIL
Road and Railway Research Laboratory		
Laboratory manager		
ir. P.N. Scheepmaker	+31 15 278 4943	p.n.scheepmaker@citg.tudelft.nl
Ing. J. Moraal	+31 15 278 4012	j.moraal@citg.tudelft.nl
Mr. J.W. Bientjes	+31 15 278 4028	j.bientjes@citg.tudelft.nl
Mr. J. Dorsman	+31 15 278 1515	j.dorsman@citg.tudelft.nl
System Administrator		
Mr. H. Man	+31 15 278 8049	h.man@citg.tudelft.nl

2 EDUCATION

The following three courses, all in Dutch, were given by Railway Engineering in the three last years of the Civil engineering curriculum:

2.1 CTvk3710/Rbk part, (Traffic, Roads and Railways), 3rd year, 50 students.

- Introduction to railway engineering
- Basic principles of wheel/rail technique
- Train loads
- Track structures
- Maintenance and renewal
- Characteristic differences between road and railway

This introductory course on railway structures is comprised of 6 lecture hours and forms part of a more general course on traffic engineering. This year railway track related exercises were incorporated in the course scheme existing of simple track calculations and a CAD-exercise of rail track structures.

2.2 CTvb4870 (Railway Engineering), 4th year, 6 students.

- Principle of railway guidance
- Layout
- Track design
- Track dynamics
- Thermal effects
- Track stability
- Rails
- Switches and crossings
- Inspection methods
- Maintenance and renewal

This basic course is comprised of 18 lecture hours and case studies and 40 hours computer aided training. A revised lecture book, in English, has been written and is undergoing some final alterations. 6 students and 2 guest students attended the lectures.

2.3 CTvb5870 (Railway Engineering, Capita Selecta), 5th year, 5 students

This course was given for the first time, replacing the old 4-years curriculum lecture e58. An overview is given of recent important developments in rail track design, construction, maintenance and management. The theme of this year was 'Ballastless railway structures'. Lectures were given partly by external specialists. Because of the special character of the course and the limited number of students, other external persons were also invited to attend the lectures. The course programme was:

Friday 15 January 1999, prof.dr.ir. C. Esveld / ir. A.P. de Man (TU Delft, Rbk).
Ballastless track: concept, development, building / Dynamic characterisation.
Friday 22 January 1999, ing. R. Nawijn / ir. D. Slager / ir. R.B. Schooleman (HSL-South)
HSL-South: Homologation / Superstructure300.
Friday 29 January 1999, ir. P.N. Scheepmaker (TU Delft, RRRL) / ir. A. Zoeteman (TU Delft, Fac. TBM)
ECOTRACK / Life cycle costs.
Friday 5 February 1999, ir. J.A. Bos (Holland Railconsult) / ir. M.H.A. Janssens (TNO-TPD)
Project Silent Train Traffic / Development silent rail.

As part of this course students were also to perform some experiments on rail track components in the laboratory. The examination of each student was based on a short essay about a course-related subject and a short report of the experiments.

2.4 Course Railway Engineering for Tramway companies.

A four days special course and workshop in tramway structures was given for an audience of 38 tramway delegates stressing the growing interest of local and regional railways in more fundamental approaches.
The following lectures, given in Dutch, were:

Friday 4 June 1999, ir. P.N. Scheepmaker / ir. J. van 't Zand
lay-out, geometric design, structural design, realisation; cases
Friday 11 June 1999, dr.ir. A.W.M. Kok / dr.ir, V.L. Markine, ir. A.P. de Man
deflection, subgrade, transition / temperature, longitudinal load /; cases
Friday 18 June 1999, ir. P.N. Scheepmaker / ir. A.J. Zoeteman
management systems / Ecotrack / Life Cycle Management; cases
Friday 25 June 1999, ir. P.K. Wiersma / prof.dr.ir. C. Esveld / ir. J.H.M. Kuipers / prof.ir. C.P. Keizer
wear / lubrication / noise / vibrations; interaction wheel-rail, cases

2.5 Completed M.Sc. studies

In the academic year 1998-1999 the following students completed their master's thesis:

Student: **H.T. Adema** (student Railway Engineering)
Date of graduation: 26 February 1999
Subject: *Finite element modelling of embedded rail structures*.
Description:
Edilon b.v. – the largest manufacturer of embedded rail systems – asked Railway Engineering to develop a finite element calculation method to predict the results of testing in laboratory. These laboratory tests are essential for approval by railway authorities, but they are quite time and money demanding. Initially, the focus of the project moved from tests on the structure in general to tests to determine component properties. These properties, the designed geometry and (train) loading specifications were input for calculations in ANSYS. Based on the results of experiments of embedded rail structures in laboratory, the general model has been tuned and improved, which finally led to a valuable tool for the both the commissioning company as for Railway Engineering.
The subject of the graduation study was the modelling of an embedded rail structure to enable a fast calculation of alternatives and to support a testing programme of this type of structure.

Fig. 2.5.1: The present design of embedded rail was modeled and several types of loading were simulated.

References: 22

Student: **J.M. Zwarthoed** (student of the Section Concrete Structures; intensive assistance (50%))
Date: 28 September 1999 (just after reporting period)
Subject: *A sleeper of reinforced concrete for light-rail applications*
Description:
A fatigue analysis was carried out on a reinforced monoblock concrete sleeper using a suitable variable load pattern. It was shown that crack width is also an important aspect. Since a design regulation for reinforced concrete sleepers is missing, the design procedure was validated using existing sleepers to reach comparable safety margins.

References: 43


Fig. 2.5.2: Reinforced sleeper design for light-rail application.

Student: **J.J.Velten** (student of the Section Structural Mechanics; little assistance)
Date of graduation: 16 April 1999
Subject: *Wave generation in overhead contact wires.*

2.6 Current Msc studies

T. Sysling, Design of a ballastless track system for High Speed Operation.
(commissioning company NBM-RAIL b.v.)

2.7 Current Ph.D. studies

ir. A.S.J. Suiker, Track deterioration under heavy axle loads (project HASLAST)

ir. A.P. de Man, Dynamic behaviour determination of railway track (project DYNATRACK)

ir. S. Rasmussen, Application of High Speed Deflectograph in roads and railways.

2.8 PAO-course

On 7 April 1999 a presentation was given by prof.dr.ir. C. Esveld, entitled 'Vibrations of TBM (tunnel drilling machine) and of its use' as part of the PAO-course 'Tunnels' (in Dutch).

3 RESEARCH PROJECTS

Programme Design

Fundamental research on railway track is performed to improve knowledge of the physical behaviour of rail track structures under repeated train loads and temperature effects. The tools necessary are dynamic modelling, optimisation, experimental testing and validation. (All these activities are assembled under one roof). The programme is organised in railway engineering research projects as is the case with road engineering. The research projects are carried out in close co-operation with external organisations. A lot of the research projects was devoted to track related problems end alternatives of the High Speed Line South project.

The following research projects were completed or are continued in the academic year:

3.1 Generic system specification of railway track. (Jan van 't Zand)

An elaborate review was performed on a proposed system of functional-only and solution-free specifications for the High Speed Line South. These basic set of specifications can be used by all parties involved in the development of the High Speed Line. The most important generic requirements, which can also be quantified, are concerned with safety (wheel-rail forces) and comfort (accelerations felt by passengers).

References: 21

3.2 Interaction between moving vehicles and railway track at high speed. (Ton Kok)

A numerical method was proposed for the analysis of vertical track behaviour as a result of moving railway vehicles. This approach has led to the development of an integrated computer software package called RAIL. The method was applied for evaluating car body accelerations, track deflections and wheel/rail forces resulting from the passage of a Thalys high-speed train, travelling on conventional ballasted track and on a non-conventional embedded rail structure. From the results presented conclusions could be drawn with respect to track structure performance under high-speed train operation.

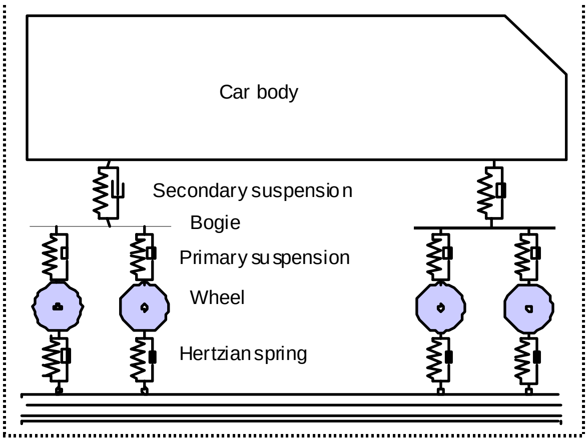


Figure 3.2.1: Modelling of a moving vehicle

References: 2

3.3 Dynatrack: an improved understanding of the dynamic behaviour of railway track. (Amy de Man)

The CROW (Dutch Information and Technology Centre for Transport and Infrastructure) started in September 1997 the 4-years Dynatrack project as a continuation of a graduate project at Railway Engineering. In the period reflected in this report, progress was made on two major branches in this project.

- First field and laboratory tests on approximately 20 different track structures and track components have indicated the wide diversity of dynamic behaviour of the structures in general (structurally) as well as in particular (in cases differing in age, use, climate and maintenance). These data will later contribute to a guideline for favourable and allowable dynamic track behaviour.
- The second branch concerns the model simulation with finite element software (i.e. RAIL). These have shown the predictability of behaviour regarding noise and vibration radiation and vehicle track interaction.

As a linking item between both, more system identification software and insight have been developed in order to extract parameter data from tested structures or components.

Fig. 3.3.1: Impulse hammer test on tramway track at the Erasmus bridge in Rotterdam

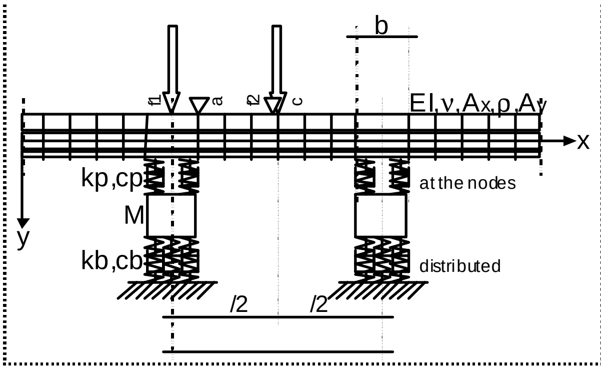


Fig. 3.3.2: Discretely supported track model in RAIL for impulse response simulations.

Research on the validity of these parameters and models is the main task for the coming phase in the project as well as improving the accessibility of the methods and assessing quality information.

References: 32

3.4 Embedded Rail: Overview of specific and important items of application of embedded rail. (Amy de Man)

CROW already started in 1997 with an inventory study on the specific and important items in the application of embedded rail. During the period covered in this report, the project almost came to an end. National railway transportation companies participated in the working group and collected attitudes, standards and experiences in order to distillate items for a wider use.

The semi-final report called ARTIS was sent to a group of roughly 50 persons regularly involved in (embedded) rail research, construction and maintenance. It stresses the wide range of possibilities and restrictions that rail structures (should) have by applying them in different situations (from tramway in city centre to high speed application).
A general guideline for composing a list of requirements is the major result of the project. The project has to be competed by the end of 1999. A follow-up is already found in optimisation of the embedded rail design (see 3.7).

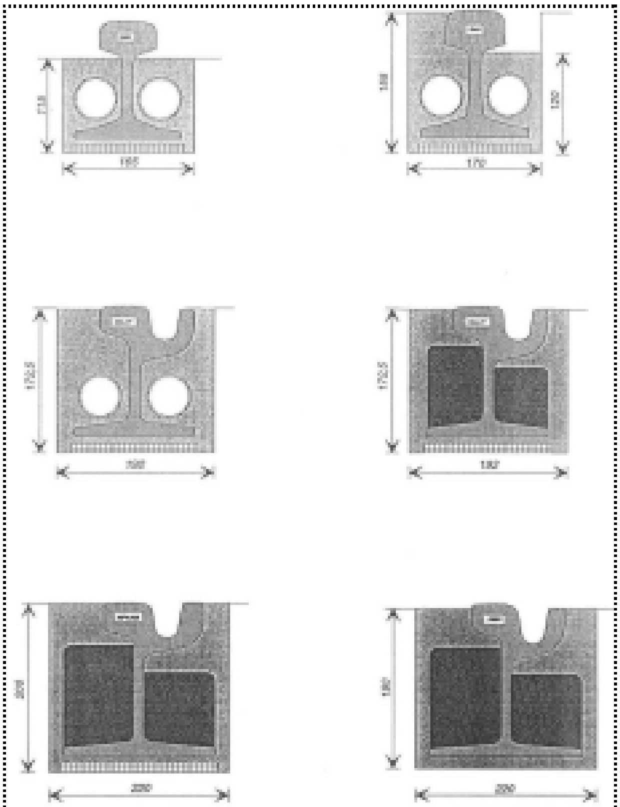


Fig. 3.4.1: Variety of embedded rail structures covered in the CROW project (courtesy picture CROW/Edilon)

References: 33

3.5 ICES-STV: Silent Train Traffic project (STT). (Amy de Man, Jan Moraal)

The main objective of the Silent Train Traffic project was to develop a 10 dB(A) more silent freight rail system, by optimising wagon, rail, super- and substructure and noise barriers. More than 30 generally Dutch companies participated in this project.
Railway Engineering has been involved in this project since the end of 1997 in an advising role. In 1998 the main contribution changed into laboratory and field tests on the newly developed silent embedded rail structure.

Fig. 3.5.1: Tests on the longitudinal elasticity of the new embedded rail structure.

Laboratory tests regarding the (quasi-)static behaviour of the designed structure contributed to several successive improvements of material properties and dimensions in order to meet predefined requirements. Dynamic laboratory and field tests at the test section at Best (Noord-Brabant province) have shown their value for the estimation of noise radiation and the argumentation of occurring effects. Though the test section has been reconstructed since then into a conventional track structure, the experiences of the STT-project are very valuable and the methodology will be applicable for much more track systems in near future.

Fig. 3.5.2: Laboratory sample of embedded SA42

Fig. 3.5.3: Field tests on the dynamic properties

References: 10, 38

3.6 Design and optimisation of a railway track structure. (Valeri Markine, Amy de Man, Coenraad Esveld)

A procedure was developed for design of railway track structures, which includes numerical modelling and dynamic analysis along with laboratory testing and optimisation.
The computer program RAIL has been used for analysis of railway structures under (high-speed) train loading. The numerical model was verified using an excitation hammer test.

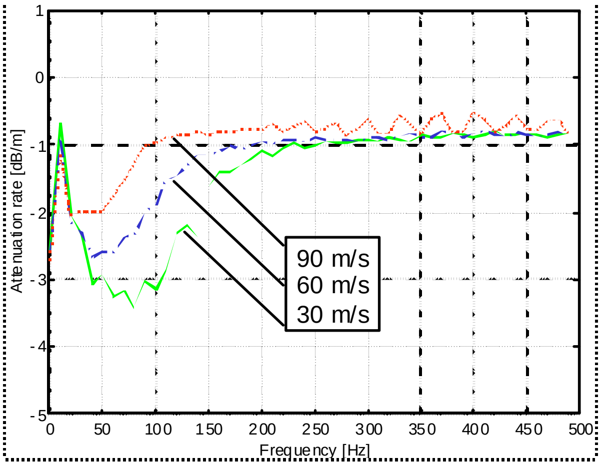


Fig. 3.6.1: Distance damping of optimum designs (multi-criteria optimisation)

The procedure has been applied to the design of an Embedded Rail Structure optimised for various train velocities. Requirements for the optimum design are related to the wear of rails and wheels, the level of acoustic noise produced by a moving train and the strength of the applied materials. To obtain the optimum design, component dimensions and mechanical properties of the track model have been varied. Mechanical properties of the ERS have also been determined using single and multiple criteria. The problems have been solved using a numerical optimisation technique.

References: 5, 13, 0

3.7 Analysis of lateral behaviour of a track using tamping machines and numerical optimisation. (Valeri Markine, Coenraad Esveld)

A procedure for determination of lateral resistance of ballast based on measurement data of shifting a real track obtained using tamping machines has been developed. Lateral behaviour of a track is described by a finite element model. The parameters of ballast characterising its lateral resistance are then determined using a numerical optimisation technique.

The procedure has been verified using the measurement results with and without extra vertical load. It has been shown that a friction coefficient between the ballast and sleepers can be obtained as well.

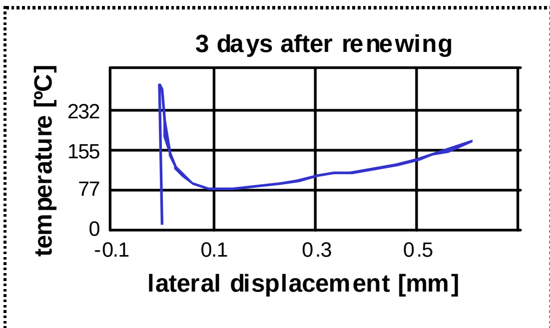


Fig. 3.7.1: Example of calculation of critical buckling temperature of track after renovation of sleepers.
Freight train, V=90 km/h; misalignment 10m/0.01m

The lateral resistance of ballast after renovation of the sleepers has been investigated and the critical buckling temperatures have been determined.

It has been shown that, basing on the safety concept given by UIC-Leaflet 720, the proposed procedure can be used for determination of safe train speed limits for tracks after renewing or after full maintenance.

References: 34

3.8 Improved knowledge of CWR track. (Coenraad Esveld)

In 1992 the International Union of Railways (UIC) commissioned a study from ERRI entitled "Improved knowledge of CWR, including switches" and the work was assigned to the ERRI D 202 Specialists' Committee. There were basically four parts to the work: a. Development of theoretical models, b. Experimental work to determine input values for the models and to validate the models, c. Revision of UIC leaflets on CWR and d. Non-destructive measurement of longitudinal rail forces due to temperature. Three models were developed: CWERRI, which analyses track stability in combination with longitudinal and vertical loads, including dynamic effects and yielding of ballast under combined load situations; LONGIN, which permits analysis of creep phenomena under longitudinal train loads and also models curve breathing; and TURN, a program which allows analysis of turnouts in combination with the finite element package ALGOR. The models were developed at TU Delft, The Netherlands and TU Kraków, Poland.

The experimental work was primarily focused on obtaining lateral track resistance data. One of the objectives was to link the European data to test data from single-tie experiments in North America. Fundamental aspects of three-dimensional ballast yield were also investigated.

References: 14

3.9 Slab track applications. (Coenraad Esveld)

Conventional track, using ballast, has been the norm for a long time. As concerning new main corridors for high speed and freight traffic, factors such as extended service life, low maintenance, availability and capacity for increased speeds and axle loads will gain in importance. Life cycle cost considerations clearly reveal the advantages of ballastless designs.

References: 19

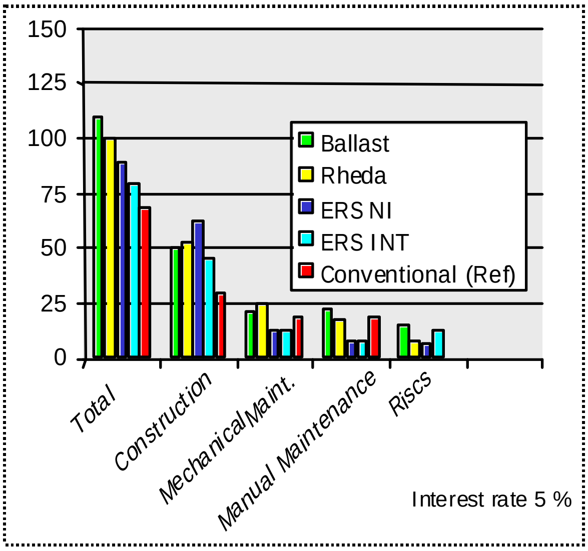


Fig. 3.9.1: Annual costs in EUR/m based on Life Cycle Cost analysis

3.10 Response of ballasted railway tracks to high axle loads (Akke Suiker)

This research focuses on the response of ballasted railway tracks to high axle loads. In general, these high axle loads may be due to:

(1) high train velocities (high speed lines),
(2) large deadweight loading (freight transport).

We will start with a brief discussion of the first category. In high-speed railway lines, the velocity of the surface waves may be of the same order of magnitude as the velocity of the train. Accordingly, the surface wave energy generated by the train may accumulate under the train wheels as time increases, which effect can be identified as resonance.

This resonance has been investigated by analysing a moving load on a granular layer that rests on a semi-infinite substratum.
Here, the granular layer is thought to simulate a ballast layer, and the semi-infinite substratum simulates a stiff foundation of concrete or rock. The moving load models an instantaneous passage of a train axle.

The granular layer has been modelled via a so-called higher-order continuum. This model has been derived from homogenisation of the micro-structural particle interaction, thereby incorporating the particle kinematics, i.e. particle displacements and particle rotations. Accordingly, size-effects by the ballast particles during high-frequency wave propagation have been investigated, showing that larger particles may lead to a stronger resonance, i.e. a larger axle load.

References: 6, 7, 39, 40

Apart from the above mentioned dynamic effects, a larger dead weight loading will also increase the train axle load. This behaviour corresponds to the second category mentioned above. During freight transportation, the loading by the train axles may be twice as high as during passenger transportation, which obviously leads to much severe loading conditions on the railway track. It is important to estimate the track settlements as a function of the loading conditions, as this provides information on the period and the type of track maintenance. Also, it may shed light on the assessment and optimisation of the track structure.

Correspondingly, the settlement behaviour of the granular components of a track structure has been measured. This experimental research has been carried out in collaboration with researchers from the University of Massachusetts. The experimental results have been compared with non-linear finite element calculations, thereby using a newly-developed material model. Currently, results by finite element calculations are compared with ‘in-situ’ settlement measurements, which is expected to provide useful insight and knowledge on the main factors of track deterioration.

References: 41, 42

3.11 Development of optimisation method (Valeri Markine)

The research here concerns improvement of Multipoint Approximations method based on Response Surface fitting (MARS method) in situations when issue of domain-dependent calculability arises which means that in some points of the design variable space the response functions can not be evaluated by the adopted simulation code. Physically, the non-existence of the response function means that an unrealistic design has been considered which cannot be analysed by a response analysis procedure. Usually, such situations lead to a premature termination or failure of the optimisation method.

In order to deal with the issue of domain-dependent calculability, some modification in the MARS method concerning planning of numerical experiments have been proposed. To demonstrate the effectiveness of the new strategy, the modified method has been applied to optimisation of dynamic behaviour of non-linear mechanical systems (Steward Platform manipulator and assembly robot) and optimisation of aerodynamic characteristics of aero foils.

This work has been done in collaboration with the University of Bradford (UK) and British Aerospace, Sowerby Research Centre (UK).

References: 4, 28, 35

3.12 HSD: High speed deflectograph for road or railway surfaces (Søren Rasmussen)

The HSD measuring device is based on a number of laserdoppler sensors mounted on a heavy vehicle. The load will cause road/rail surface to deflect and the velocity of that movement is picked up by the sensors. Deformations of the track structure under various conditions are simulated using the RAIL program. The results forms the basis for the development of a model for the interpretation of the data from the HSD with respect to structural discontinuities, track stiffness and bearing capacity. A similar approach is adopted for roads based on results obtained with the Veroad program.

Fig. 3.12.1: Test set-up for high speed deflectometer measurements

A prototype for use on roads is expected to be operational this summer.

References: 36

4. PRESENT RESEARCH FOCUS

The slab track design can be considered as the standard structure for future railway applications because of the fact that classical ballast track can no longer meet the modern standards regarding reliability, availability, maintainability and safety. From the two fastening systems that come with slab track, direct fastenings and embedded rail, the latter is more attractive from the viewpoint of life-cycle costs, structure height and noise. However, the potentials of embedded rail track should be exploited further by optimisation techniques based on thorough theoretical and experimental research.

In high speed train application dynamic effects become dominant. Moreover, models which describe the dynamic interaction between railway track, the vehicles and the supporting structure should be used rather than quasi-static models of the track only. On the other hand, large computer models are complex, not easy to handle and time-consuming. For quick references, an elegant solution is the integrated dynamic model RAIL, which can run on a normal PC via a user interface. Experiences so far justifies the generalisation of this model.

The economical service life of existing ballast tracks is still substantial, making it worthwhile to seek for more effective maintenance methods of this type of track. For instance, simultaneous optimisation of geometry and stiffness parameters during the tamping/stabilising process might be possible to improve homogeneity. It is also interesting to consider the upgrade of existing ballast track into ballastless slab track in an industrial process.

Considering the new developments in railway design the use of concrete in building railway track and structures may become a very dominating material. Many technical problems in the field of Railway Engineering can only be solved in close co-operation with other civil branches like Road Engineering (highly mechanised slab track realisation, use of EPS), Concrete Structures (slab track and sleeper technology), Structural Mechanics (Risk analysis) and Underground Building (interaction between railway track and deformable tunnel tubes). Also, interdisciplinary aspects should be included in railway track research and/or education programmes. Among them are dynamic interaction between railway track and vehicles (Vehicle Engineering), stray current problems (Electrical Engineering) and life-cycle costs and decision systems (Systems Management).

The concept of magnetic trains becomes more and more viable. The first commercial applications will be on isolated lines. The high speed effects of the load transmission via the magnetic 'rails' onto the supporting structure should be analysed in case of discontinuities of the 'running' surface. A system of save allowable tolerances should be established given the impedance characteristics of the vehicles. To advance the introduction of magnetic trains a new research field might also the study the possibility of hybrid track structures (mixing conventional and magnetic track) to enable a certain class of magnetic trains to also use existing track.

5 MISCELLANEOUS

5.1 Co-ordination Committee Railway Engineering

This co-ordination committee Railway Engineering consists of representatives from railway companies, public service departments, CROW and TU Delft Railway Engineering (Esveld holds chairmanship). In this academic year the committee met four times. By now three working groups are active:

- 'Track management/Decision support systems'
- 'Embedded Rail'.
- 'Dynatrack'

5.2 CUR/COB project L400

The project committee L400 Vibrations has developed a prognosis model for vibrations, 1st part, presented on the COB-day, June 1999.

5.3 Nomenclature Committee

The participation in the CROW nomenclature committee, working group 4, 'Railway Structures' was continued but reduced to some expert advises and supplying graphical material.

5.4 Delft Cluster

A proposal, listing a number of relevant railway research projects was forwarded, to the Delft Cluster organisation to join and participate in the research programme Line Infrastructure. The proposed subjects are:

- Generalisation the of RAIL program;
- Degradation model of track geometry;
- Critical speed HSL-track;
- Dynamic behaviour of track structures;
- Application of High speed deflectograph
- Optimisation of embedded rail structure
- Life-cycle management
- Optimisation Light Rail track

5.5 Advisory Counsel Infrastructure and Traffic

Prior to the official visitation of the education programme of the sub-faculties Civil Engineering and Geodetic Engineering, the Advisory Counsel of Infrastructure and Traffic was asked In March 1999 to react to a draft document 'Strength and Weakness Analysis of the Section Road and Railway Engineering'. Proposed improvements were, aimed at Railway Engineering:

- more flexibility in choosing modules, especially in the basic part of the curriculum;
- development of a wider profile, introduction of project management, vehicle and electrical engineering.

5.6 External contacts

In the reported academic year a frequent contact existed with the following companies, institutions and other organisations, who join an interest in railway infrastructure:
home: Arcadis, Bolit, C.R.O.W, CUR/COB, DSM, Edilon, ERRI, HTM, HRC, ICES-STV, Nigtevegt, NS-RIB, NSTO, Oranjewoud, PHZI, Siemens Nederland, Strukton Railinfra, NBM Amstelland Bouw&Infra, Volker Stevin Rail & Traffic.
abroad: Clouth, CDM, KU Leuven, NMBS, Pandrol, Phoenix, Vossloh, British Aerospace (Sowerby Research Centre), Institut Teknologi Bandung (ITB).

5.7 Computer support

The management of the local network Road and Railway Engineering was taken over on 1 May 1999 by the I&A (Information and Automation) service group of the faculty. Also a new file server was installed with much more capacity. For local services, a new system administrator was appointed. The Railway Engineering web site (http://www.ct.tudelft.nl/railbouwkunde/index.htm) is updated regularly and contains now also an ftp-site with actual information for students and other authorised people. Student assistants are involved in updating databases and the Intranet of the whole section Road and Railway Engineering.

6. PUBLICATIONS

1. Esveld, C., Kok, A.W.M. and Man, A.P. de, Integrated numerical and experimental research of railway track structures. Fourth International Workshop on Design Theories and their Verification of Concrete slabs for Pavements and Railroads, Conference Portugal, 1998.09

2. Esveld, C., and Kok, A.W.M., Interaction between moving vehicles and railway track at high speed. REI / Edition 1998, no. 3, 1998.10

3. Esveld, C., Annual Report Chair for Railway Engineering, period 1/9/1997-31/8/1998. Rbk 1998.10

4. Markine, V.L., Meijers, P., Toropov, V.V. (1998). Optimization of workspace of a manipulator for a flight simulator using multipoint approximation method. Paper AIAA-98-4955. ISBN 1-56347-273-2, 1998.09

5. Markine, V.L., Esveld, C. Kok, A.W.M., Man, A.P. de and Toropov, V.V., Optimization of a High-Speed Railway Track Using Multipoint Approximation Method. AIAA-98-4980, 1998, ISBN 1-56347-273-2, 1998.09

6. Suiker, A.S.J., Chang, C.S., De Borst, R. and Esveld, C., (1999) Surface Waves in a stratified half space with enhanced continuum properties - Part 1 - Formulation of the boundary problem, *European Journal of Mechanics A/Solids*, **18**, pp. 749-768.

7. Suiker, A.S.J., Chang, C.S., De Borst, R. and Esveld, C., (1999) Surface Waves in a stratified half space with enhanced continuum properties - Part 2 - Analysis of the wave characteristics in regard to high-speed railway tracks, *European Journal of Mechanics A/Solids*, **18**, pp. 769-784.

8. Suiker, A.S.J., Chang (University of Massachusetts) and De Borst, R., Micro-Mechanical Modelling of Granular Material, 1998

9. Esveld. C., Application possibilities of concrete in railinfra. Concrete Infra Day 27 October 1998, 1998.10 (in Dutch)

10. Man, A.P. de and Moraal J., Mechanical testing of the definitive SA42-rail structure in behalf of the ICES project, ICES-TUD, Report 7-98-111-7, 1998.10 (in Dutch).

11. Esveld, C., Ballastless track concepts: fast and economical. Dutch Road Congress, 3 December 1998, 1998.12 (in Dutch).

12. Zand, J. van 't, Noise and Vibration in Rail Track Curves, Projectplan CROW, 1998.12

13. Markine, V.L., Man, A.P. de, Esveld, C., A procedure for design and optimization of a railway track structure. Proc. Interactive Conference on Cost Effectiveness and Safety Aspects of Railway Track, Union Internationale des Chemins de Fer, Paris, 8-9 December 1998. 1998.12

14. Esveld, C., Improved knowledge of CWR track. Interactive Conference on Cost Effectiveness and Safety Aspects of Railway Track, Union Internationale des Chemins de Fer, Paris, 8-9 December 1998. 1998.12

15. Esveld, C., Lecture notes CTvk371, Traffic, Roads & Railways, Part C: Railways (revised reprint). TUD/If, 50 p.,1999.01 (in Dutch).

16. Esveld, C., Lecture notes CTvb4870, Railway Engineering (revised version). TUD/RBk, 199 p.,1999.01

17. Kok, A.W.M., Markine, V.L. (1999) Dynamic phenomena in the gutter of an embedded rail structure. Report 7-99-122-1, Laboratory for Road and Railway Engineering, Delft University of Technology. ISSN 0169-9288 (in Dutch), 1999.01

18. Moraal, J., Static and dynamic tests on rail fastenings systems. TUD Report 7-99-118-3, 1999.01 (confidential)

19. Esveld. C., Recent developments in slab track application, Rail Tech Europe, 1999.02

20. Zand, J. van 't, Optimisation of Embedded Rail Structures, Projectplan CROW, 1999.01 (in Dutch)

21. Zand, J. van 't, Review of Generic System Specifications of Track, Rapport 7-99-110-23, 1999.02 (in Dutch, confidential)

22. Adema, H.T., Finite element modelling of embedded rail structures, Rapport 7-99-120-7, 1999.03 (in Dutch, confidential)

23. Esveld. C., Vibrations of TBM (tunnel drilling machine) and of use. PAO-cursus Tunnels, 1999.04 (in Dutch)

24. Moraal, J. Laboratory tests on rail fastening systems, TUD Report 7-99-118-4, 1999.05 (confidential)

25. Markine, V.L., de Man, A.P., Esveld, C., Toropov, V.V. Use of a numerical optimization technique for design of a railway track structure. Short Paper Proceedings of 3-rd World Congress of Structural and Multidisciplinary Optimization, Buffalo, NY, USA, May 17-21, 1999, pp. 206-208, 1999.05

26. Zand, J. van 't and Scheepmaker, P.N., Lay-out and geometric design., Part 1a course for tramway companies, Course notes 1999.06 (in Dutch).

27. Zand, J. van 't, en Scheepmaker, P.N., Structural design and realisation, Part 1b course for tramway companies, Course notes 1999.06 (in Dutch)

28. Toropov, V.V., Markine, V.L., Holden, C.M.E. Use of mid-range approximations for optimization problems with functions of domain-dependent calculability. Short Paper Proceedings of 3-rd World Congress of Structural and Multidisciplinary Optimization, Buffalo, NY, USA, May 17-21, 1999, pp. 338-340, 1999.05

29. Esveld, C., Prognosis model for vibration1 nuisance. COB-Day, 1999.06 (in Dutch)

30. Moraal, J., Pulling tests on glued rail joints. Report 7-99-103-7, 1999.06 (in Dutch).

31. Esveld. C., Slab Track: A competitive solution. Rail International/Schienen der Welt, June 1999. 1999.06

32. Man, A.P. de, Embedded rail: the dynamic behaviour of structures UIC54 en SA42 (Dynatrack project), Rapport Vbk 7-99-111-8, 1999.07 (in Dutch)

33. Man, A.P. de (red.), ARTIS – Recommendations and directives of embedded rail structure applications, interim version (CROW working committee Embedded Rail), 1999.07 (in Dutch).

34. Markine, V.L. and Esveld, C., Analysis of Lateral Behaviour of a Railway Track Structure Using an Optimisation Technique. Vbk Report 7-99-124-1, 1999.07

35. Markine, V.L. Toropov, V.V., van Keulen, F., Alvarez, L.F. (1999) Multipoint Approximations Based on Response Surface Fitting: a Summary of Recent Developments. Proceedings of the Ist ASMO UK/ISSMO Conference on Engineering Design Optimisation, Ilkley, West Yorkshire, UK, July 8-9, 1999.07, pp.371-381. ISBN 0-86176-650-4

36. Hildebrand, G., Rasmussen, S., Andres, R., Development of a laser based High Speed Deflectograph, Nondestructive Testing of Pavements and Backcalculation of Moduli, Seattle, 1999.07

37. Man, A.P. de, Embedded rail: measurements and analysis of dynamic behaviour of structures UIC54 en SA42, Rapport 7-99-111-9, 1999.08 (in Dutch)

38. Man, A.P. de and Moraal, J. To more silent track: results of laboratory tests as part of the ICES-STV project, Land+Water 7/8, 1999.08 (in Dutch).

39. Suiker, A.S.J. and De Borst, R., (1999) de, Critical response of a granular railway track under high train velocities., In Pande, G.N., Pietruszczak, S. and SChweiger, H.F., *Proceedings of the Seventh International Symposium on Numerical Models in Geomechanics* - NUMOG VII, Graz, Austria, pp. 297-302. Balkema, Rotterdam, The Netherlands.

40. Suiker, A.S.J. (1999) Resonance behaviour of ballasted high-speed railway tracks, In *XI Panamerican Conference on Soil Mechanics and Geotechnical Engineering*, Foz do Iguassu, Brasil, pp. 865-874.

41. Suiker, A.S.J. (1999) Static and Cyclic loading experiments on non-cohesive granular materials, Technical report 1-99-DUT-1, Faculty of Civil Engineering, Delft University of Technology, Delft, The Netherlands.

42. Suiker, A.S.J. Esveld, C. and Frenkel, R. (1999) On the modeling of track deterioration, In *Innovations in the Design and Assessment of Ralway track*, Delft, The Netherlands, pp. 1-14.

43. Zwarthoed, J.M., A sleeper of reinforced concrete for light-rail applications. Main report DUT/Concrete factory Nigtevecht, 1999.09. (just after reporting period). (in Dutch)

Delft, January 2000,

Prof.dr.ir. C. Esveld

Professor of Railway Engineering