FINNISH RAIL ADMINISTRATION

RHK • Technical Unit

Publications of
the Finnish Rail Administration

A
6/2001

FINAL REPORT

250 kN and 300 kN AXLE LOADS

o Matti Levomäki

o Jarkko Valtonen

Helsinki 2001

FINNISH
RAIL
ADMINISTRATION

Publications of
the Finnish Rail Administration A 6/2001

FINAL REPORT

250 kN and 300 kN AXLE LOADS

o Matti Levomäki

o Jarkko Valtonen

Helsinki 2001

RHK
FINNISH RAIL ADMINISTRATION
KAIVOKATU 6, P.O.Box 185
FIN-00101 HELSINKI

TEL. +358 9 5840 5111
FAX +358 9 5840 5140
E-MAIL: info@rhk.fi

ISBN 952-445-052-6
ISSN 1455-2604

Levomäki, Matti and Valtonen, Jarkko: Final Report, 250 kN and 300 kN axle loads. Finnish Rail Administration, Technical Unit. Helsinki 2001. Publications of the Finnish Rail Administration A 6/2001. 47 pages an 1 appendix. ISBN 952-445-052-6, ISSN 1455-2604.

Key words: rail traffic, axle loads

SUMMARY

This is the final report of the Finnish Rail Administration's (RHK) research work which is aimed at introducing 250 kN and 300 kN axle loads. The study began in the summer of 1998 and was completed by the end of 2000.

The results of the research work are briefly presented in this report, as well as suggestions for further research and actions resulting from the different investigations. Actions necessary for raising the present axle loads are also listed in this report. The report is based on the previously published research reports and interviews with experts. According to the investigations, it is possible to raise axle loads to 250 kN on certain conditions. On the basis of this investigation it cannot be said with certainty whether an axle load of 300 kN is possible.

The most important statements arising from the investigations are briefly summarised as follows:

- The introduction of higher axle loads emphasises the need to treat the railway track as a common entity, where the permanent way and substructure are in balance. In addition, the material of each layer should have the strength and grading properties corresponding to the requirements arising from the increased axle loads.

- A load of 120 kN/rail metre is used as a traffic load in track stability calculations. The load is expected to affect the track vertically and impulses are included. According to the existing information, the metre load used covers the 300 kN axle loads with two- and four-axle-wagons. It is not possible to increase the metre load on the present tracks.

- It is possible to increase axle loads with the new bogies of new generation wagons without essentially increasing dynamic loads on the track.

- Wheel loads and admissible forces were not included in this investigation. The new UIC leaflet no. 505 regarding the measurement of rolling stock running behaviour will allow at least a 200 kN vertical wheel load instead of the present 170 kN.

- If axle loads are increased, the most serious problems on the present railway network would be damage to insulated joints, the rapid wear of switches (crossings, tongues and curved middle area rail), base plates sinking into wooden sleepers made of softwood, a change of track gauge in switches, more rapid wear of grade 220 (700) rail materials, an increasing need for maintenance in curve sections, an increasing number of breakages in aluminothermic welds and the breaking of

sleepers. The incidence of 113-failure according to UIC rail defect catalogue would probably increase.

- It is possible to raise axle loads to 250 kN on a superstructure with 60 E 1 or 54 E 1 continuous welded rails, concrete sleepers on the line and concrete or hardwood sleepers in switches, S-type insulated joints or an axle-counter system and switches with a large radius of curvature. Sleepers are the most problematic aspect and hence attention should be paid to speed limits. The 250 kN axle load is possible with soft-wood sleepers only with continuous welded rails and apparently at a maximum speed of 60 km/h. New concrete sleepers would have to be designed in a new way. It is not possible to raise axle loads to 250 kN outside railway yards when the rail is 43 kg or less or jointed track. Fastenings, pads or side insulators do not hinder the raising of axle loads. Only small radii of curvature may have a poor impact on insulators.

- Loads according to Design Instructions for Railway Bridges (abbreviated to RSO) cover the 250 kN axle loads. Where heavier axle loads are concerned, the load model has to be changed. A new load model (α*LM71) has already been made for 300 kN axle loads. When bridges in poor condition are detected during the main inspection of bridges, there will be no hindrance to the use of 250 kN axle loads. Provision for e.g. 30 % heavier axle loads increases the construction costs of a bridge by only 3 %.

- The raising of axle loads to 250 kN does not significantly affect the degradation of ballast, if the cumulative traffic amount does not grow and the ballast is firm. The degradation of railway ballast in a track with concrete sleepers is markedly higher than in a track with wooden sleepers. The strength category for the track section should be chosen by comparing life cycle costs.

- Raising the axle load is not possible on a gravel ballasted track

- Asphalt structures in tracks have many advantages which can be utilised in track construction.

- All culverts are different from each other, although a marked regularity among the same type of culverts can be noted. In particular, it is difficult to specify the condition of stone culverts lengthened by concrete pipes. It is very difficult to estimate the impact of raising the axle load on the behaviour of even a well-known and documented culvert.

- Heavy freight traffic without doubt causes vibration. The general opinion is that the raising of axle loads increases vibration. In practice it is impossible, both economically and technically, to eliminate vibration completely.

- On the basis of samples taken from the frost insulation plates it could be seen that the plates had born stresses rather well, with the exception of the production lot which had previously been noticed to be of inferior quality. Thus, the characteristics of the frost insulation plates presently produced are sufficient with the present axle loads and mounting procedures.

- On the basis of the calculation model created the increase of damage caused by the raising of axle loads from 225 kN to 250 kN is 22 – 35 %, depending on the magnitude of the safety coefficient which is chosen for the load directed at the plate e.g. due to a defective mounting depth and dynamic loading.

- The increase of the damage to frost insulation plates due to the raising of axle loads to 250 kN can be prevented by tightening the compression strength property of the plate from 450 kPa to 500 kPa.

- The dimensioning of frost insulation to correspond to Nordic conditions guarantees a sufficient thickness of substructure layers for all conceivable axle loads.

- The quasi-static modelling of the vertical stiffness of a railway embankment based on the linear elastic layer model corresponds well to the behaviour of the actual railway embankment measured in the instrumented track. The mechanical behaviour of layer materials and subsoil should be described by a model taking the effects of the stress level into account. The parameters of the model should be determined in the laboratory at the stress and deformation level corresponding to the real loading conditions.

- Track maintenance costs will increase by less than 5 % if the highest permitted axle load is raised from 225 kN to 250 kN. In theory the costs will increase by 5 %, but in reality all axle loads will not be 225 kN in all axles, and they would not all increase to 250 kN. The final rate will vary depending on the amount of traffic and the distribution of axle loads on each track section.

FOREWORD

The research work regarding the needs for changes and measures required by the possible introduction of 250 kN and 300 kN axle loads was started at the Finnish Rail Administration's (RHK) Technical Unit in the summer of 1998 and was completed by the end of 2000. The research comprises of 19 RHK's publications and 2 publications of the Technical Research Centre of Finland (VTT).

The research work has been supervised by a steering group composed of the following members: Markku Nummelin, Pasi Leimi and Kari Ojanperä RHK, Technical Unit, Olli-Pekka Hartikainen, Jarkko Valtonen, Iikka Järvenpää and Matti Levomäki from the Helsinki University of Technology (TKK), Raimo Uusinoka and Pauli Kolisoja from the Tampere University of Technology (TTKK) and Seppo Kähkönen from ANSERI-Konsultit Oy. In addition, the following persons have acted as experts and investigators in the different studies: Harry Harjula, Juha Heinonen and Vilho Roos from VR-Track Ltd, Esko Sandelin from RHK, Pasi Niskanen, Erkki Mäkelä and Antti Nurmikolu from TTKK, Pekka Haakana, Lauri Salokangas, Jouko Lehtomäki, Joni Harju, Petri Ketonen, Jani Meriläinen and Mikael Fröberg from TKK, Matti Hakulinen from Geomatti Oy and Wladimir Segercrantz from VTT. Additionally, numerous foreign and domestic experts have been interviewed during the journeys which were made in connection with the research.

The results of the research work are briefly covered in this final report. In addition, suggestions for further investigation and actions resulting from the different studies are presented and the necessary measures to be taken in order to increase axle loads on a railway section are listed in this report. This final report is based on previously published research reports and interviews with experts. The report has been compiled by Matti Levomäki and Jarkko Valtonen in the Laboratory of Highway Engineering at the Helsinki University of Technology in Otaniemi, Espoo.

Helsinki, April 2001

Finnish Rail Administration
Technical Unit

CONTENTS

APPENDICES

1. INTRODUCTION

This final report presents the results of the different studies included in the investigation aimed at introducing 250 kN and 300 kN axle loads. Suggestions for further studies and measures, as well as the necessary actions to permit the use of heavier axle loads than the present ones are covered in the report. The final report is based on earlier published investigation reports and interviews with experts.

The most important observations and results of each study are briefly reported in chapters 2 – 11. The interview and fact-finding journeys made in connection with the investigation are described in chapter 12. The measures which are to be taken in order to introduce heavier axle loads are presented in chapter 13. In the last chapter there is a summary of the results of the whole investigation.

The amount of money used for the investigation aimed at introducing higher axle loads totalled about € 0.7 million (about 4.1 million Finnish marks).

2. PRESTUDY

The research project began in 1998 with a prestudy on the existing material by firstly making a literature search and later a preliminary literature study on instrumentation.

Report A1/1999 (ISBN 952-445-014-3, ISSN 1455-2604, 73 pages) was published by the Finnish Rail Administration under the title: **Literature study of the instrumentation of rail structure, 250kN and 300 kN axle loads**.

The material was divided into 15 different categories with respect to the eventual raising of axle loads. The categories are:
Rolling stock, geometry, rails, rail fastenings, sleepers, ballast bed, substructure, bottom layer, bridges, switches, vibration, maintenance, basic publications and instrumentation.

Basically the list includes all the publications, memos, standards, research results, seminar reports, articles and other written material which are even remotely related to the subject. The list includes over one thousand titles.

The following basic information has been given on all publications: authors, the publisher, the year of publication, the eventual ISBN or other number, the number of pages and possibly also suitable chapters and where the item can be found. The literature search is a source book for further studies.

The literature part of the prestudy is mainly a source book for reference when planning the instrumentation of a railway structure. The list consists of research reports related to instrumentation, memos and other publications, which can be used later, both when planning instrumentation and when making actual measurements.

3. RAILWAY TRAFFIC INDUCED GROUND VIBRATION

Railway traffic induced ground vibration has been investigated in several places on the railway network. On the existing railway network the handling of matters related to vibration are divided into the risk survey on vibration, which is related to land use planning, the survey of the extent of vibration, and the measurements indicating how harmful the vibration is. The literature study on railway traffic induced ground vibration consists of a short presentation of the origin and drift of vibration. In this investigation the main interest has been focused, however, on the impact of heavier axle loads on the origin of vibration, as well as on structures and other methods used in order to attenuate vibration.

Report A 3/1999 (ISBN 952-445-019-4, ISSN 1455-2604, 37 pages) was published by the Finnish Rail Administration under the title: **Railway traffic induced ground vibration, 250 kN and 300 kN axle loads**.

Relating to land use planning, several reports have been made of the risk surveys, vibration measurements and local descriptive studies on vibration. These have not been published by the Finnish Rail Administration but a summary of them is given in this connection.

The following can be stated as conclusions on the impact of heavy axle loads on vibration and the methods used in order to attenuate vibration.

- There is no doubt that heavy freight traffic causes vibration. This fact has been stated in measurements made in Finland.
- The raising of axle loads, linear density and train length increases vibration. Due to the variation in local circumstances all research results are not similar.
- Apart from the features of the rolling stock and embankment, the soil conditions, foundations of buildings and methods of construction, as well as the number of layers and the locations of buildings, among other factors, affect the local variation of vibration strength.
- A piled foundation for railways eliminates vibration almost completely.
- It is usually best to attenuate vibration or prevent the spread of vibration as near to the origin of the vibration as possible.
- When planning to attenuate vibration, one should be extremely familiar with the local circumstances.
- In practice, it is impossible, both technically and economically, to eliminate vibration completely.

RHK will be participating in the "Joint Nordic Railway Vibration Research Project - NORDVIB". The investigation of railway traffic induced ground vibration will be continued on the railway network.

4. BRIDGES

4.1 Summary

A preliminary study on the capacity of bridges on the Rautaruukki (Raahe) - Haparanda line (total 145 bridges) has been made during this research work on the basis of the layout drawings and calculations for several bridges. The α*LM71 load model, in addition to the partial safety coefficients for the load and material of the present design instructions, have been used in the study. The VR-98 load model which was presented in the research report has been renamed to the corresponding pan-European load model, α*LM71. It has been determined in the study whether the permitted axle load can be raised from the present 225 kN to 250 kN, or even up to 300 kN.

Report A 7/1999 (ISBN 952-445-026-7, ISSN 1455-2604, 23 pages) was published by the Finnish Rail Administration under the title: **Classification and Inventory of Railway Bridges on the Rautaruukki - Haparanda Line to Increase Permitted Axle Loads**.

When bridges in poor condition are detected during the main inspection of bridges, this will not form any hindrance to the use of 250 kN axle loads. As a result of the inspection the bridges have been divided into risk categories according to which some criteria for repair, maintenance and renewal procedures at different levels have been found. The new load model of α*LM71 should be used in the planning as soon as possible.

When the capacity of bridges is reviewed using the α*LM71 load model with the partial safety coefficients for load and material according to the present design instructions, it can be seen that 44 % of the bridges on the Rautaruukki - Haparanda line belong to a risk category in which the raising of axle loads up to 300 kN cannot be permitted, 27 % of the bridges should be inspected before the raising of axle loads, and 29 % of the bridges do not call for any action at all. According to the total length of bridges on the line, the percentages are correspondingly 16 %, 49 % and 35 %.

If specific trains instead of load models and minor partial safety coefficients for load are used, the percentages will be altered as follows: 20 % of the railway bridges belong to a risk category where the raising of the axle loads up to 300 kN cannot be permitted, 55 % of the railway bridges should be inspected before the raising of axle loads, and 25 % of the railway bridges do not need any action at all.

4.2 Common criteria, measures and observations

If no calculations are available on substructures i.e. foundations, a special inspection should be made of the bridge, in which the condition of the structure as well as the capacity of eventual wooden piles should be checked. Apart from the material measurements, the gross tonnage to which the bridge has been exposed during its whole lifetime affects the fatigue capacity of bridges on the line. When calculating the value of the accumulative tension in the Design Instructions for Railway Bridges the value given for the life cycle of 100 years is a traffic flow of 19 million gross tons/track/year for the specific trains in 1975 - 2000. The gross tonnages on this line are considerably less. Their fatigue impact is minor due to the lower axle loads of the specific trains during the first half of the century compared to those of the latter half of the century. (Report 1570 of the Technical Research Centre of Finland, "The useful life time of steel bridges", page 21)

The impact of the design load and the accumulated gross tonnage can be taken into account in the way mentioned in *ENV 1993-2, Eurocode 3, Part 2*. Regarding those line sections where the 250 kN axle load is already being used, the maintenance and inspection measures should be intensified on bridges which have been dimensioned for I-48 and an older load model in order to detect any preliminary weakening of the bridge condition. If the calculated capacity of a bridge with the design load has been reached, strengthening or renewal measures are required before the service load can be raised.

In the repair of old bridges and the planning of new bridges the α*LM71 load model should be introduced as soon as possible. In the repair design the capacity of old bridges should be examined with the α*LM71 load model. Axle loads have continually been rising throughout the existence of the railway. Making provisions for e.g. 30 % higher axle loads will increase the construction costs by only 3 %. If the traffic management costs during the construction work are taken into account, the rise in the overall costs is minor even. The renewal and repair of bridges will take time, which has to be taken into account when deciding whether 300 kN axle loads are to be permitted in rolling stock running on the railway network.

Types of bridges and structural parts whose capacity should be checked more closely:

- The crossbars in old steel bridges and secondary longitudinal girders, which have had a high number of load cycles during their lifetime.
- Old slab portal bridges with one opening; the structures may need some reinforcement.
- Old bearing beds or bearings, especially in short bridges.

Types of bridges and structural parts needing considerable strengthening or renewal of structures, if the axle load is increased to 300 kN (design basis α*LM71):

- A reinforced concrete bridge with one opening, which is designed in accordance with I-48 or an older load model and with a span of less than 15 m.
- A steel bridge with one opening, which is measured in accordance with I-26 or an

older load model and with a span of less than 27.5 m.

- A steel bridge with one opening, which is measured in accordance with the I-48 load model and with a span of less than 17.5 m.
- A concrete or steel bridge with one opening, which is measured in accordance with the VR-74 load model and with a span of less than 5 m.
- Old foundations, often so-called "kallmur"; no calculations can be found.
- Piled abutments, with mainly vertical wood piles in pile groups.

Types of bridges and structural parts which might need considerable strengthening or renewal of structures with the present axle load of 250 kN (design basis VR-74):

- A reinforced concrete bridge with one opening, which is measured in accordance with I-48 or an older load model and with a span of less than 6 m.
- A steel bridge with one opening, which is measured in accordance with I-26 or an older load model and with a span of less than 22.5 m.
- A steel bridge with one opening, which is measured in accordance with the I-48 load model and with a span of less than 10 m.
- Old foundations, often so-called "kallmur"; no calculations can be found.
- Piled abutments, with mainly vertical wood piles in pile groups.

4.3 Further measures

The inspection shows that 250 kN can fairly well be used on bridges on the Rautaruukki - Haparanda line. Before higher axle loads can be used, a theoretical capacity inspection and a special inspection should be made of part of the bridges. In order to carry out such inspections, calculation instructions should exist by means of which the capacity of the present structures can be calculated.

The capacity inspection should cover at least the following points:
- special inspections
- material tests on the specimen taken from the bearing structures
- inspection on the design of the structures
- more precise calculations in regard to bearing capacity
- fatigue inspections and evaluation of the remaining lifetime.

The impact of the impulse ratio is important in the design load. By improving the quality of the rolling stock the impact of the impulse can be decreased. The impulse is minor on a line in good condition. As far as old steel bridges without a ballast bed are concerned the characteristics of the rails can be improved by casting a damping layer between the steel structure and sleepers. In old steel bridges the capacity of secondary structures in particular can be improved in this way. This technique should be developed.

5. ROLLING STOCK

In conjunction with the literary study, another study was made to ascertain how the eventual raising of axle loads affects the dynamic loads caused by rolling stock and the rolling stock itself .

Report A 3/2000 (ISBN 952-445-031-3, ISSN 1455-2604, 62 pages) was published by the Finnish Rail Administration under the title: **Literary Research on Rolling Stock, 250 kN and 300 kN axle loads**.

A train causes both vertical and horizontal dynamic forces, which are all transmitted to the track through contacting surfaces the size of a thumb nail. The dynamic load in the vertical direction is caused by the defects in the rail and wheel, as well as by the change in track stiffness in the vertical direction. There are two main components of the dynamic wheel-track contact load. The low frequency load (below 10 Hz) is caused when the contact point is moving forward at the train speed. The high frequency load is caused by the irregularities of rail and wheel, the most important of which is wheel flat. The force effect of the wheel flat is almost directly comparable with, and roughly estimated to be twice to four times as large as, the static load. If the axle load increases one should react very critically to wheel flats.

The following can be stated, among others, as the results of the study:

- The impact of wheel flat depends on the length of the wheel flat, the wheel load, the unsprung mass, the running speed and the elasticity of the track.
- The durability of the rail against the bending fatigue due to the train load can be calculated, but there are many parameters at work and these are difficult to specify accurately.
- 250 kN and 300 kN axle loads require new rolling stock whose dynamic load should be studied during the type approval process, when the maximum permitted speeds are also specified.
- Strengthening of wheel and rail using a special finishing has proved to be a good method, according to Swedish experiences.

The impact of enhanced bogie types on resistances to motion and the energy consumption of locomotives should be studied. A necessary subject for further study could be to examine the train's running behaviour with the help of simulation. One should obtain information in particular on forces affecting the wheel contact. The best way to start is by becoming acquainted with the foreign simulation studies.

6. BALLAST AND SUBSTRUCTURE

The aim of the literary study was to summarise the effects the raising of axle loads would have on the ballast bed and substructure. In the ballast study the aim, based on literary and our own test results, was to estimate the quality of the most favourable railway ballast with respect to different life cycles and investment costs.

Report A 6/1999 (ISBN 952-445-025-9, ISSN 1455-2604, 135 pages) was published by the Finnish Rail Administration under the title: **The Literary Research of Ballast and Substructure, 250 kN and 300 kN axle loads**.

In addition, the ballast study, report A 4/2000 (ISBN 952-445-032-1, ISSN 1445-2604, 93 pages), was published by the Finnish Rail Administration under the title: **Effects of Strength on the Life Cycle of Railway Ballast**.

Principle issues to be investigated in the ballast bed were the ballast degradation and matters affecting it, as well as the most profitable life cycle economics for the selection of ballast grade for different traffic volumes. In the substructure the investigation was focused on the material quality requirements, the required dimensions of the structural layers and the available material models applicable in the modelling of the mechanical behaviour of railway structures, including the typical values of the parameters of these models. In addition, the quality requirements for frost insulation plates used in railway embankments and the feasibility of using asphalt materials in railway structures were also studied.

The following can be stated as conclusions of both studies:

- The degradation of ballast can be decreased by the following methods:
  - Impact stress on the ballast bed which arises in rail joints, bad welding joints, on an uneven rail, in damaged track parts and due to worn wheels, should be minimised.
  - Tamping should be minimised. The sinking of the embankment and subsoil should be minimised and thus the need to tamp down.
  - The fouling content in the ballast should be minimised when the ballast is being laid and it is necessary to make sure that the grading offers a sufficient amount of voids in the ballast.
  - A rigid rail must be used.
  - A hard and tenacious stone material, which will not be exposed to decay, should be used.
  - Cubical stone material should be used.
  - Fouling entering the ballast bed from upwards, mainly from open wagons, should be minimised.
  - The ballast bed should be thick enough and the intermediate layer should have the correct grading, so that the substructure will not penetrate to the ballast bed.
  - The ballast bed should have good drainage.
- The degradation of ballast will become more rapid if wooden sleepers are replaced by concrete sleepers.

- The cumulative traffic flow on the line section has been proved to have the most important effect on the degradation of ballast and thus the life cycle of the ballast bed.
- A longer life cycle of the ballast bed is achieved by high quality ballast, but generally the investment costs will also rise. The strength category should be chosen for the line on the basis of comparing the life cycle costs.
- As far as life cycle costs are concerned, long transportation of ballast may be the most reasonable solution on lines with a high annual traffic flow. Thus, on lines with low traffic flow the cheapest ballast is often the most economical as well.
- On the basis of the investigations in the USA and Sweden, the raising of axle loads from 250 kN to 300 kN and further up to 350 kN does not significantly increase the degradation of ballast, if the cumulative traffic flow is not increasing and the ballast is firm, as it usually is in Finland.
- Introducing higher axle loads emphasises the need to treat the railway track as a common entity where the permanent way and substructure are in balance. In addition, the material of each layer should have the strength and grading properties corresponding to the requirements arising from the increased axle loads.
- In the substructure, the increased axle loads have the most profound effect on the intermediate layer and in the upper part of the insulation layer. Consequently, thought should be given to increasing the thickness of the intermediate layer from its present level (150 mm). Furthermore, one should avoid using materials with very uniform grain size, low strength or poor weathering resistance.
- In the climatic conditions prevalent in the Nordic countries dimensioning of the railway track against frost guarantees that the structural layers of the railway embankment are thick enough for all possible axle loads.
- Before raising axle loads to 250 kN, the width of the track embankment should be changed to bring it in line with the Technical rules and guidelines for track (RAMO), part 3 ”Track Structure”. A closer study should be made to ascertain whether the embankment is wide enough for over 250 kN axle loads.
- Asphalt track structures have many advantages which can be utilised in track construction. They require, however, more study in the Finnish climate. In particular, the effects of the winter conditions are not well enough known.
- The vertical stiffness of the railway structure (‘track modulus’) can be modelled in a relatively simple manner by using a linear elastic layer model. However, the parameters describing the mechanical behaviour of the layer materials should be known as functions of the stress level.
- More sophisticated calculation methods - primarily the finite element method (FEM) - are required when modelling the effect of the railway embankment width. Even in this case it is important to calibrate the results of the modelling against observations made from actual railway structures and, if possible, also from instrumented railway embankments specially designed for this purpose.

7. CULVERTS

7.1 Field survey of culverts

Report A 8/1999 (ISBN 952-445-027-5, ISSN 1455-2604, 27 pages) was published by the Finnish Rail Administration under the title: **Field study on culverts, 250 kN and 300 kN axle loads**.

The first phase of the study consisted of listing the culverts in the Oulu and Kemi track districts according to the culvert registers. Following this, some culverts were studied in the field on the line section between the Rautaruukki Oyj railway yard at Raahe and Tornio.

On the basis of the first phase of the study, it can be estimated that heavy axle loads have the following effects:

- All culverts are different from each other, although a marked regularity among the same type of culverts can be noted.
- It is very difficult or even impossible to make any profound comments on old culverts. It is hard in particular to define the condition of stone culverts lengthened by concrete pipes.
- Stone culverts in the main seemed to be in good condition. On the Swedish ore line, stones in stone culverts have been found to move under a heavier axle load, causing, for example, ballast to flow into the culverts.
- In some places concrete structures were in a fairly bad condition.
- The foundations of culverts cannot generally be estimated visually at all. The foundations have most often been made on gravel.
- The information in the culvert register is not particularly accurate enough. It is even possible that some culverts have not been included in the register at all.
- It will be very difficult to estimate all the effects of heavy axle loads, even on well documented culverts

The following can be stated about the line between Rautaruukki and Tornio:

- If heavier axle loads are occasionally going to be used on the line between Tornio and Rautaruukki, all the culverts should be studied. A walking inspection should be carried out very carefully. On the basis of walking inspections one can detect damaged culverts and become prepared for repairs.
- It is not enough to check the condition of culverts by a walking inspection only. As with bridges, a main inspection should also be made of the culverts every 10 years. At least the reporting should be improved. The inspection system and the register of culverts should be improved.
- The instructions for planning repairs to culverts should be improved. One should make sure, by means of an investigation based on structural calculations and

modelling of culverts, that the bearing capacity of structures is valid for heavier axle loads than the present ones.

7.2 Further studies on culverts

After the field study on culverts the investigation was continued in cooperation with Banverket (BV), Jernbaneverket (JBV) and the Finnish Rail Administration (RHK). For the purpose of this cooperation, a report was made on the most common Finnish culvert types, structures and materials.

Report A 2/2000 (ISBN 952-445-030-5, ISSN 1455-2604, 36 pages) was published by the Finnish Rail Administration under the title: **Bantrummor**.

In Finland, Sweden and Norway culvert structures are very similar, as well as the problems related to the building and maintenance of culverts. In order to establish as wide an empirical basis as possible, expertise relating to the measurement, structure, repair and maintenance of culverts is being gathered from each country, and on the basis of this the possible needs for investigation can be concluded. Finally, the aim is to produce common Nordic instructions for the measurement, building and maintenance of culverts, or at least to utilise the best Nordic experience for producing the instructions and to prevent possibly making the same mistakes again. Through this cooperation, culvert information available in each country from completed investigations or those still in process will be available for common use. Based on the reports, it will be possible to assess whether further studies or experimental culvert building are necessary.

On the basis of the prestudy a further study has been started in Finland. The aim of this study is to define stresses caused by different sized train loads in different kinds of loading circumstances on the culvert structure with the help of deformation measurements and mathematical modelling of the measuring results made for the concrete pipe culverts. Based on this, the structural strength of track culverts can be estimated in their actual loading situations.

Thus far, a few field measurements have been made on the test site in Viiala. In addition to the deformation of concrete pipes, the values measured have also included earth pressures and strains prevailing in the track embankment, vertical forces on the rails and the vertical movements of one sleeper. The measuring results will be analysed with the help of computer simulations based on a finite element method with the loading situation corresponding to the present permitted axle loads and the 250 kN and 300 kN axle loads. A study on a smaller scale is currently being carried out in Sweden on the deformation of stone culverts on the ore line under 300 kN axle loads.

On the basis of the information obtained from the culvert study which is being carried out in Finland and the common Nordic study, general specifications for the building, repair (e.g. lengthening techniques), maintenance and inspection of culverts will be made at a later date.

8. INSTRUMENTATION AND MODELLING

The instrumentation plan contains the instrumentation methods for track structure, the work phases, costs and the handling of results of the instrumentations which were carried out in the 1999 summer on the line between Kouvola and Koria, at a distance of 187 km +580 m from Helsinki.

Report A 4/1999 (ISBN 952-445-020-8, ISSN 1455-2604, 30 pages) was published by the Finnish Rail Administration under the title: **Plan for instrumentation and modelling a railway track, 250 kN and 300 kN axle loads**.

The aim of the instrumentation presented in the plan is to obtain information on the magnitudes and distributions of stresses and strains induced by train loads on the railway structure. The measurements enable testing of the usefulness and reliability of the modelling of rail and track structure to be carried out, and later on an estimation of the possibilities of increasing the permitted axle loads to 250 kN and 300 kN.

Report A 5/2000 (ISBN 952-445-033x, ISSN 1455-2604, 137 pages) was published by the Finnish Rail Administration under the title: **Instrumentation and modelling of track structure, 250 kN and 300 kN axle loads**. Most of the report was also translated into English and published by the Finnish Rail Administration, Report A 10/2000 (ISBN 952-445-042-9, ISSN 1455-2604, 99 pages) under the title: **Instrumentation and modelling of track structure, 250 kN and 300 kN axle loads**.

Conclusions

Generally the results and the analyses of the measurements made at the Koria instrumentation site can be considered to confirm the conclusions reached in connection with the literary study on ballast and substructure. Thus, the following can be stated:

- The quasi-static modelling of the vertical stiffness of a railway embankment based on the linear elastic layer model corresponds well with the behaviour of the actual railway embankment measured at the instrumentation site. The mechanical behaviour of layer materials and subsoil should however, be described by a model taking the effects of stress level into account. The parameters of the model should be determined in the laboratory with the stress and deformation level corresponding to the real loading conditions.

- It is clearly more difficult to specify a sufficient width of railway embankment in regard to stability corresponding to different sized axle loads in long-term repeated loading than to carry out the modelling of the vertical stiffness of a railway embankment. Although the modelling work done so far has not given any direct answer to the problem, the measuring results at the instrumentation site provide a clear indication that in certain parts of the railway embankment there will exist horizontal cyclic tensile strains with high axle loads. The more stronger these tensile strains reappear, the greater the proportion of them which will remain irreversible. This will be seen along the whole railway embankment as a gradual increase in flatness.

Need for further investigations

The following can be stated about the application of modelling work describing the mechanical function of the railway embankment and the need for further investigations:

- On the basis of the modelling work done thus far it seems that a modelling environment can be constructed to describe the vertical stiffness of a railway embankment. This enables us to anticipate theoretically the vertical stiffness of railway embankments, the structure of which is known, and the effect of stresses and strains directed at rail structures. In order to obtain an approximate result from a rail embankment one should know at least the thickness and grading of the layers, as well as the type of subsoil. If necessary, a more accurate estimate can be obtained by testing the properties of the layer materials and subsoil under laboratory conditions. First, it should be checked whether the existing modelling programmes (e.g. GEOTRACK) can be used, so that the software development would not become unreasonably expensive.

- It is proposed that the studies concerning whether the embankment width is sufficient be continued, initially by theoretical studies based on the use of more sophisticated modelling tools - primarily the use of the finite element method. With this we can attempt to obtain a clear idea of how the railway embankment is functioning physically and where the critical points are situated in regard to the stability of the railway embankment. The results of the theoretical modelling could be applied to the detailed planning of a single instrumentation site which would serve in the verification of theoretical modelling.

- As an addition to the measurements made in Koria during the 1999 summer, it is suggested that another series of measurements should be carried out. The railway embankment should be mostly frozen, so that on the basis of the results one could evaluate, for instance, how the increasing stiffness due to the freezing of the embankment affects the stresses on track components and the magnitude of the vibration spreading to the track environment. Winter measurements would give a more reliable basis for separating the deformation in the subsoil from the overall changes in the rail embankment detected during the measurements in the 1999 summer. Naturally, this is always provided that the measuring instruments inside the embankment remain functioning until the new measuring period. The instrumentation for the rail must be rebuilt.

9. FROST INSULATION PLATES

9.1 Prestudy on frost insulation plates

The study involved digging out samples from frost insulation plates and ballast at Turenki railway yard. The position of frost insulation plates were also investigated together with VR-Track Ltd. The frost insulation report was not published.

As conclusions of the study the following can be stated in regard to the frost insulation plates and the effects of eventual heavy axle loads:

- All the frost insulation plates used may not necessarily bear even the present axle loads without becoming broken or moist, because plates which have suffered from production problems have also been installed.
- The method of installation, installation depth and protection do apparently affect the durability of the plate surface rather a lot. Under heavier axle loads the surface of a plate may be damaged more quickly.
- Ballast degradation gathers moisture on top of the plates.

The study on frost insulation plates was continued by taking samples in Siilinjärvi and Inkeroinen. The further study was reported as an appendix to the prestudy. Some observations from the further study are as follows:

- The plates which were installed in the lowest parts were the least damaged.
- It was noteworthy that even within the course of one year the surface of plates may become damaged and water can penetrate into the plate, resulting in the thermal insulation of a plate becoming weaker in relation to the water absorbed into the plate.
- However, 19 year-old plates were not in such a bad condition as was suspected, in fact quite the contrary. The two layered structure and sand isolation maintain the insulation capacity well. On the other hand, according to the later study two plates on top of each other will become more moist than one plate which is as thick as the two together.

With only a few samples it is not possible to obtain any reliable information on the present situation with respect to frost insulation plates, as plates produced by several manufacturers and different production methods have been installed. The investigation on the condition of the existing frost insulation plates will be continued by studying frost insulation plates of different ages and made by different manufacturers.

9.2 Study on the technical specifications of XPS frost insulation plates

The investigation on frost insulation plates was continued with the study on the technical specifications of XPS frost insulation plates. The study focused on the theoretical and experimental investigations required by the technical specifications on new frost insulation plates. Report A 2/2001 (ISBN 952-445-047-x, ISSN 1455-2604, 97 pages) was published by the Finnish Rail Administration under the title: **XPS Frost Insulation Plates in track structure, 250 kN and 300 kN axle loads.**

The following conclusions can be given as the results of the literature study and laboratory tests on samples taken from the track and performed on unused plates:

- The product standard which is under preparation for XPS plates will unambiguously determine the characteristics to be tested on plates and the testing methods. Later the manufacturer will be responsible for bringing the product in line with the standard and thus eligible for CE-marking.

- The estimate of the amount of moisture absorbed by the XPS frost insulation plate, which meets the present requirements, is considered to be 0.25 – 0.30 vol.% annually. Accordingly, a 10 – 12 vol.% moisture content will be achieved during the 40-year service life required for the frost insulation plate. Using the present blowing agents the design value for the thermal conductivity will be clearly exceeded during the life time due to the moisture absorption. This is because the present blowing agents will diffuse from the cells of the plate much faster than the heavy molecule gases in use earlier, which accelerate the ozone depletion and greenhouse effect. Thanks to their lower-than-air thermal conductivity they also caused a lower thermal conductivity in the plate itself.

- On the basis of samples taken from plates which have been part of the track structure for 3 – 10 years, it can be said that frost insulation plates have borne stresses in more or less the desired way, with the exception of four samples in exceptional poor condition. These most probably belonged to the production lot which even earlier had been stated to be of poor quality. The moisture content of other samples varied from 0.9 to 3.4 vol.% and in four plates chosen from these the thermal conductivity, measured at an average temperature of 10 °C, was below 0.036 W/Km. It can thus be stated that the characteristics of the plates are sufficient for the present axle loads.

- Ballast grains penetrating into the plate from the ballast bed are causing depressions on the upper surface of frost insulation plates. How this affects the function of the frost insulation plate is taken into account in the frost insulation design by removing 10 mm from the thickness of the plate. Thus, the depressions due to ballast grains cause considerable extra costs, in particular with thinner plates. For instance, 17 % of the purchasing costs of a 60 mm plate can be considered to be spent in compensating the depressions by making the plate "too" thick. In order to decrease the depressions a reasonable way of coating a frost insulation plate with a stiff filter fabric or a backing net should be invented.

- The flatness and bearing of the plate installation tray affect the origin of depressions and cracks considerably, and through this also the moisture content, and hence the thermal conductivity. The bearing capacity required for the underlying layers of frost insulation plates should be determined so that no uneven depressions increasing the bending stresses of frost insulation plates would appear under repeated cyclic loading. Namely, these increase the need for track tamping and thus the costs.

- Raising the loading level in a fatigue test simulating cyclic stress on a frost insulation plate increased the permanent compression developing in the test in an exponential way. There is a trend-setting correlation between the plate's compression strength and the compression developing in the fatigue test. However, the fatigue test cannot be completely replaced by the compression test.

- On the basis of the calculation model created, the increase of damage in the frost insulation plate when the axle load is raised from 225 kN to 250 kN, is 22 – 35 %, depending on the size of the safety coefficient chosen for the loading, e.g. due to a defective mounting depth and dynamic loading. Calculated in a corresponding way the increase in damage when changing over from 225 kN to 300 kN axle load is 82 – 146 %. The increase in damage can be prevented by tightening the compression strength requirement of the plate up to 500 kPa when changing over to 250 kN axle loads and up to 600 kPa when changing over to 300 kN axle loads.

10. TRACK

10.1 General

The aim of the study was to discover how the raising of the axle load affects the rails, fastenings, switches and sleepers. Apart from becoming acquainted with the literature, visits to working sites and plants were also made, and experts were interviewed in conjunction with the study. A calculation program was developed for the evaluation of concrete sleepers. A theoretical treatment of track stresses, based on Zimmermann/ Eisenmann method, was added at the beginning of the report.

Report A 3/2001 (ISBN 952-445-048-8, ISSN 1455-2604, 90 pages) was published by the Finnish Rail Administration under the title: **Railway Track Study, 250 kN and 300 kN axle loads**.

10.2 Rails, welding and rail joints

Rails

The following can be stated as conclusions of the rail study:

- The raising of axle loads to 250 kN (or up to 300 kN) is possible on tracks with 60 E 1 or 54 E 1 –rails and
  - continuous welded rails
  - concrete sleepers on the line and concrete or hardwood sleepers in switches
  - S-type insulation joints or an axle counting system
  - switches with a large radius of curvature.
- The 60 E 1 –rail enables axle loads to be raised to 300 kN, but the 54 E 1 –rail only, with some reservations, to 250 kN.
- Axle loads cannot be raised to 250 kN outside railway yards, when there is a 43 kg/m or a lighter rail or jointed track on the track section. Grade 220 (700) rails will wear more rapidly and the need for maintenance will increase on curve sections as axle loads are raised.

Welding

The breaking capacity of weldings was tested with bending tests made for the joint welds which were collected by the Kaipiainen kiskohitsaamo (Rail Welding Plant) and from Kouvola – Inkeroinen and Joutseno track sections. According to the test, one cannot draw any far reaching conclusions on the welded seams, as all three welding methods (aluminothermic welding, arc-joint welding and flash butt welding) are quite reliable with the present axle loads. However, the following can be stated as conclusions of the effect of high axle loads:

- On the basis of the research results we can be confident that the present welded joints will bear at least 250 kN axle loads. The most decisive factor with regard to different welds is probably that the welding procedure is successful. The age of the weld probably has no great significance to the durability. The effect of loading on welding seams caused by train traffic could not be clarified with this test series.

- Aluminothermic welding will endure better with grade 220 (700) rails than with grade 260 (900) rails. The durability of flash butt welds is better with grade 260 (900) rails.

- It is presumable that with heavier axle loads the rather small fault density would somewhat grow, as the smallest damages would appear easily with heavier loading.

- A fish-plated rail joint hole does not have any significance to the durability of the welding seam. The pores possibly appearing in the welds will affect the durability more at the foot area than at the head. Welds should be studied more so that compression would appear from underneath the rail. In this case, there would be tension on the running surface of the rail and surface damage could be seen better. It is presumable that the results obtained now would change.

- A long term follow-up study should be done to new welds most preferably at the area where heavy loading would appear or could be arranged. Welding should be done in bad weather in order to discover the influence of the weather on bending durability and bending flexure during the welding procedure.

Joints

An insulated rail joint combines the rail ends, keeps them together and prevents angles from forming in the stretch of rails in the lateral and vertical plane. Heavy stress is directed at the rail joints i.e. at their points of discontinuity, and a lot of maintenance work is required there. Breakages of fish-plated rail joints are very common even with the present axle loads and the raising of axle loads may multiply the number of breaks even with careful estimation.

With regard to the present rail joint types only the S-type rail joint will probably faultlessly withstand the raising of axle loads to 300 kN. The assembly of this joint is problematic; an S-joint element glued in the work shop requires two aluminothermic welds. The durability of traditional joints can, however, be improved by sawing off the head of the rails at an angle of 30° instead of at perpendicular angle. In this case the stress caused by the axle would be divided more evenly over the rail joint and the fish-plate would be exposed to minor stresses.

The most certain way to eliminate rail joint breaks is to change over to a so-called axle counting system in the signalling technology, so that no insulated rail joints will be needed.

10.3 Rail fastenings, etc.

Base plates penetrating into wooden sleepers might turn out to be problematic. In a switch with wooden sleepers the bearing strength of the sleepers is a more critical feature than the endurance of the fastenings. With the raising of axle loads rail fastenings used have no significance to the dimensioning, although there have been problems with high axle loads in Rautaruukki Oyj's steel factory in Raahe. The design of the presently used rubber pads tolerates the rise in axle loads well. The side insulators of concrete sleepers do not constitute any hindrance to the raising of axle loads except for the very small radii of curvature.

10.4 Switches

The following conclusions can be made on the switches in the Vainikkala and Rautaruukki Oyj's Raahe railway yards, which were included in the study on switches:

- In general, the investigation has proved that switches are firm entities which can tolerate even high loading and demanding circumstances. Measuring tolerances will actually be exceeded, but surprisingly few critical excesses occur. However, all switches undergo deformation under high loading, resulting in reversible changes to the gauge. Appreciable permanent dimensional changes are caused by the wearing of different element parts, such as the tip of the tongue and crossing, as well as the bent middle area rail and check rail. The real estimation of the results is hampered by the fact that switches may have been repaired or adjusted between the measuring times, resulting in a change in the dimensions in one direction or the other.

- The critical points in switches are the tongue rail, the bent middle area rail, the crossing and the check rail. The measuring deviations of switches equipped with concrete or hardwood sleepers mainly constitute changes due to the wearing of the rail, whereas measuring deviations in switches with softwood sleepers are also caused by the penetration of base plates into the sleeper.

- It is presumable, however, that with regard to the wear of switches the speed is the basic issue with higher axle loads. In addition, the effect of the stability of vertical and lateral geometry on the durability of switches is obvious. A poorly tampered switch will "live" more under train traffic and the wearing of different elements will increase. The wearing of the tongue rail especially will increase considerably when the wheel does not touch the rail surface in the desired way.

The following can be stated as conclusions of the switch study:

- Long, single switches on 60 E 1 rails and equipped with concrete sleepers will tolerate at least 250 kN axle loads.

- Short, single switches on 60 E 1 rails and equipped with concrete sleepers will probably tolerate 250 kN axle loads, at least at low speeds.

- Long, single switches on 54 E 1 rails and equipped with concrete or hardwood sleepers will probably tolerate 250 kN axle loads.

- Short, single switches on 54 E 1 rails and equipped with concrete sleepers will probably tolerate 250 kN axle loads, at least at low speeds.

- All diamond crossings with slips included in the study were on 54 E 1 rails and equipped with wooden sleepers. It can be said that diamond crossings with slips would probably tolerate at least 250 kN axle loads at low speeds.

- The tamping of switches will be more significant as a poorly tampered switch will "live" under a train and it will stress the tongue rail, among other components, considerably.

- It is to be assumed that with heavier axle loads stresses on critical points such as tongue rails, the bent middle area rail, check rail and crossing will increase. With heavy axle loads the fault rate of switches would also grow, which would increase maintenance costs as well.

- Switch inspections should be increased so that incipient faults can be eliminated in good time.

Additional inspections of switches should be made by choosing a few switches which would be monitored for a longer time. During the investigation one should record everything done to the switch, such as supports, measurements and repairs. The ideal situation would be for new switches to be included in the study on a track section with maximum loading.

10.5 Sleepers

The following can be stated on the basis of the sleeper study:

- Design instructions for concrete sleepers are based on German standards from the 1950s. Only the moment resistance of a sleeper is taken into account in the instructions. However, the shear resistance is in many cases more decisive in regard to the sleeper strength than the moment resistance. The design instructions should be checked. In this connection foreign opinions may also be needed.

- With the track modulus at 0.3 and 0.4 most sleepers fulfil the requirements set by the 250 kN axle load. Where the track modulus is 0.4 and the rail 54 E 1, the speed must be reduced in many cases to below 80 km/h. When the rail is 60 E 1, no speed limits are required. With a track modulus of 0.5, there are minor opportunities for raising axle loads.

- A 300 kN axle load is not possible with safety coefficient 2, which was used in the calculations.

- The exceeding of sleeper moment resistance does not directly endanger train safety, but the exceeding of shear tolerance may do so. Hence, when designing new sleepers one should consider how the shear tolerance can be increased.

- With softwood sleepers a 250 kN axle load is possible only on continuous welded rails and apparently at a maximum speed of 60 km/h.

- Whatever the case, sleepers cause problems, which explains why one should pay attention to speed limits.

- New sleepers should apparently be designed in a new way.

- According to experts, sleepers which have been manufactured after 1986 will tolerate a raising of axle load up to 250 kN.

11. MAINTENANCE

How higher axle loads affect the maintenance and maintenance costs was investigated in a master's thesis in the Laboratory of Highway Engineering at the Helsinki University of Technology (TKK). The source books used comprised domestic and foreign literature, and research reports ordered earlier by RHK. Interviews were also made in this connection. The starting point in the work was the material which had been collected in connection with the literature search. The aim of the study was to estimate, with the help of literature and interviews, how the raising of axle loads from 225 kN to 250 kN will affect the maintenance costs.

Report A 4/2001 (ISBN 952-445-050-x, ISSN 1455-2604) was published by the Finnish Rail Administration under the title: **Literature study on the track maintenance costs, 250 kN and 300 kN axle loads**.

The study focused mainly on the track and ballast, which includes the ballast bed, sleepers, rails with fastenings and joints, as well as switches. The results also include the impact on the rail maintenance costs as a whole.

The following can be stated as conclusions of the literature study and interviews on the effect of high axle loads on maintenance and maintenance costs:

- According to the Swedish and American investigations the raising of the axle load from 250 kN to 300 kN and further to 350 kN does not significantly increase the degradation of ballast, if the traffic flow does not increase and the ballast is firm. The Finnish ballast is generally firm. There are no research results available on the effect of increasing the axle load from 225 kN to 250 kN on the ballast bed, but on the basis of the effects of the above-mentioned 300–350 kN it is presumable that the increase does not significantly affect the degradation of ballast. This also explains why there will not be any noteworthy changes in the maintenance costs of the ballast bed. At the points of discontinuity, such as insulation joints and bridge ends, a stronger impact force on the ballast bed may, however, increase the need for maintenance.

- Wear on rails increases with higher axle loads. In any case, the rail, among all the track components, has the greatest effect on maintenance costs. It may even contribute 25 % of the total costs. A harder steel grade, heavier rail or a suitable surface finishing will resist the wear better. Higher axle loads will probably speed up the appearance of short-pitch corrugation on the rail. A suitable rail type for higher axle loads is a continuous welded rail. Small radii of curvature (below 600 m) will speed up wearing of the rails.

- The need for repair and exchange will increase in the wearing parts of switches, so the maintenance costs for switches will increase. The contribution of switches towards the maintenance costs is considerable in any case. It can represent as much as 15 % of the total track maintenance costs.

- Of the track maintenance costs in general, about half are dependent on the traffic. The half of the maintenance costs are due, among other things, to maintenance and snow removal from the railway yards, electric equipment and signalling. The amount of the latter varies in different winters according to the weather. Maintenance costs due to traffic will grow by less than 10 %, if the maximum permitted axle load is raised from 225 kN to 250 kN.

- Track maintenance costs will grow by less than 5 %, if the maximum permitted axle load is raised from 225 kN to 250 kN. In theory, the costs will rise by 5 %, but in reality all the axle loads will not be 225 kN for all axles and they will not all rise to 250 kN. The final rate depends on the track section and the distribution of axle load.

12. JOURNEYS

12.1 Russia

Moscow

During the research work, the axle loads used in the Russian railways and their future plans were studied at the All-Russia Railway Research Institute in Moscow. The travel report was published as a publication of the Technical Research Centre of Finland, abbreviated to VTT (Research report 501/1999) under the title: **Research on the effects of 250 – 300 kN axle loads on railway measuring parameters and rail maintenance in the Russian railways**.

The former Soviet Union was lacking in railway capacity. An attempt was first made to resolve this problem by bringing in longer trains. The next step was to introduce a 257.5 kN axle load; such traffic was permitted in 1985 - 1991. The experts considered the trial to be satisfactory although the need for spare parts for bogies increased considerably. The track and ballast came through the experiment well. However, rail fastening supplies were used in maintenance to a much greater extent than before. In regard to the substructure, the experiment in some places was catastrophic even, especially for over 3 metre-high embankments. Bridges caused some trouble as well.

In 1999, the maximum permitted axle load for freight wagons was 235 kN and for locomotives 250 kN. In the future the aim of the Russian railways is to raise the axle load on important main lines. For this reason, an extensive research and development programme on rolling stock and railway network was launched. The aim is to permit a 250 kN axle load at a speed of 120 km/h in 2005. The most important and expensive measures are directed both at the improvement of substructure and bridges, and at the development of rolling stock.

Diagnostic train

During the research work we became acquainted with the diagnostic train at the test station in Scherbinka. The research report was published as a publication of the Technical Research Centre of Finland, Communities and Infrastructure (Research report 571/2000) under the title: **Diagnostic train**.

The accuracy of a single measurement by the diagnostic train is not particularly good. An average of ten measurements is in fact required to provide reliable information. The average of the measuring results is calculated over a journey of one hundred metres in the actual analysis, so that the scatter of the results decreases. The scale difference between Finland and Russia is obvious. In Russia, this method clearly produces new information with long measuring periods, but in Finland the same kind of result can be obtained by just examining the base map (1:20 000). Single problems will not be detected with this measuring accuracy. Another problem with the interpretation of the results obtained by the diagnostic train is related to the subsoil. The characteristics of the subsoil are not taken into account at all in the Russian interpretation method, but the same elasticity coefficient will always be used with the subsoil as with the rail embankment. If the train is to be used in Finland, the calculation method should be changed in this respect.

Nowadays, it seems that it is not worthwhile hiring the diagnostic train for use in Finland. The most serious problems are the inadequate handling of the subsoil in the interpretation of the test results, the deficient knowledge on the deformation tolerances suitable for Finnish circumstances, and the limited measuring accuracy of the equipment.

12.2 Sweden

Luleå

A visit to Luleå was made in connection with the research project. The main interest was focused on the investigations made by the Luleå University of Technology (LTU) and on Banverket's iron ore line. The travel report has not been published. Some observations from the travel report are:

There are a total of 800 culverts on the iron ore line. Five of these were damaged during the first test run with a heavy train (300 kN). 100 culverts have already been repaired. A total of 60 % of all culverts will be repaired or renewed. This will cost about 100 million Swedish crowns.

Bridge openings should be placed in the direction of flow, which brings costs savings due to concrete reinforcements. In Finland, bridge openings have traditionally been made perpendicularly to the track, which means that the bridge usually has to be built longer.

Concrete gravel is local and fairly good in quality but slightly varying (by visual estimate Finnish classes R2 - R3). Ballast should be cleaned for the whole width of the substructure (the Swedes have a new machine for this) so that water will not accumulate under the railway. If the ballast is cleaned under the track only, the sideways easily bank water.

There were small ore pellets present in the gravel along the line. If the pellets are durable enough, they will support the ballast bed, but if they break they will change the character of the water permeability (most likely the pellets will be ground). How the pellets affect the ballast bed is currently being studied. An attempt has been made to remove pellets by vacuuming as they are not magnetic (hematite). The mechanism in the bottom hatches of wagons has been improved to make it more durable.

The unsprung mass of the Russian 245 kN and Swedish 300 kN axle load wagons is apparently the same. The Swedish wagons are kept in good condition, however, so there is some reason to assume that the wagons will correspond to each other in terms of the stresses on the rail, despite the Russian axle load being lower.

The Swedish railway embankment is considerably wider than the Finnish one. This can affect the stability of the line. In spite of the wider embankment, catenary supports are evenly canted outwards from the line. Heavy trains have obviously caused stress on the side of the embankment.

The 300 kN axle load project was introduced in Sweden in 1995. Banverket has invested 140 million Swedish crowns annually in the maintenance of its ore line. Of this, 30 million Swedish crowns have been spent on rails. MTAB (the iron ore company) has invested 40 million Swedish crowns annually in the maintenance of wagons. Half of this has been spent on wheels. Research carried out in Canada has been made use of in the project (similar climate). Other universities in Sweden are also participating, but with minor significance. The starting points in the study were: load, traffic, coldness and climate.

As there was no centralised research in the railway section and the ore line clearly demanded this, the JvtC (Järnvägstekniskt Centrum, Centre of the Railway Technology) was established. The 300 kN axle load studied is the highest in Europe. The cold climate, mixed traffic and previous investigations on light traffic only served to increase the interest in the study. Transport expenses are reduced by 15 % if a longer ore train than normal is used (250 kN axles / 52 wagons). The effect is 30 %, if the axle loads are increased to 300 kN. The track maintenance costs will grow, however, by less than 10 %. A heavier axle load decreases gross tonnage, i.e. the relative share of wagons in the mass decreases.

Stockholm, Gothenburg and Borlänge

An interview in Stockholm at the Royal Institute of Technology (abbreviated to KTH) was carried out in connection with the research project. The aim of the trip was to interview KTH's experts on vibration and to obtain information on the factors affecting vibration and reducing it.

Additionally, a visit to Gothenburg, Chalmers University of Technology, Department of Solid Mechanics, was made in order to become acquainted with the local experts. The subject of the mini-seminar organised in Gothenburg was the static and dynamic behaviour of the railway line.

A visit to Borlänge was made in connection with the maintenance study. The aim of the visit was to interview Banverket's experts and to obtain some information on maintenance, and especially on the effects of heavier axle loads on maintenance costs.

13. MEASURES BEFORE RAISING AXLE LOADS

13.1 250 kN axle loads

On the basis of this study the raising of axle loads to 250 kN is possible on the following conditions.

Loads

- The highest dynamic wheel load in the vertical direction is 170 kN and in the lateral direction 70 kN.

Signalling

- Speed limits for wagons exceeding 225 kN shall be programmed in the automatic train protection system.
- The speed and running restriction list shall be created for sidings.

Track and ballast

- On track sections between stations there shall be
  - either 54 E 1 or 60 E 1 rails
  - continuous welded rails
  - concrete sleepers, wooden sleepers only after careful consideration
  - S-type insulated rail joints
  - preferably an axle counting system in signalling technology
  - a ballast bed according to part 3 “Track structure” of the Technical rules and guidelines for track (RAMO)
  - a maintenance level of at least 3 according to part 13 ”Track inspection” of the Technical rules and guidelines for track (RAMO).

- At stations there shall be
  - switches on concrete or hardwood sleepers
  - preferably high-speed switches
  - at least 43 kg/m rail
  - no spike fastenings or small base plates
  - jointed tracks are possible when the joints have been made according to part 3 ”Track structure” of the Technical rules and guidelines for track (RAMO).
  - a ballast bed, even in switches, according to part 3 ”Track structure” of the Technical rules and guidelines for track (RAMO)
  - special restrictions on gravel ballast.

Substructure

- Switch areas, embankment width included, are changed and implemented according to part 3 “Track structure” of the Technical rules and guidelines for track (RAMO).

Bridges

- Bridges with defects in load-bearing structures, which have been detected during the main inspection, have been repaired.

- Types of bridges or structural parts requiring a capacity study, considerable reinforcement measures, or the renewal of structures:
  - A reinforced concrete bridge with 1 opening, which is measured in accordance with I-48 or an older load model and with a span of less than 6 m.
  - A steel bridge with 1 opening, which is measured in accordance with a I-26 or an older load model and with a span of less than 22.5 m.
  - A steel bridge with 1 opening, which is measured in accordance with a I-48 load model and with a span of less than 10 m.
  - Old foundations, often so-called "kallmur"; no calculations can be found.
  - Piled abutments, with mainly vertical wood piles in pile groups.

- Repaired bridges shall fulfil the requirements of load model VR-74.

Stability and vibration

- An inventory of the bottom layer of the track section has been made with the help of the existing bottom layer research information. The bottom layer research information shall be completed with bottom investigations and calculations, if necessary.

- On the existing tracks the minimum total safety coefficient is 1.2 with a load of 120 kN/ track metre. The structures have been repaired where necessary. The total safety coefficient of 1.2 allows raising of the axle load to 250 kN.

- The total safety coefficient of improved track bottom layers shall be at least 1.5.

- On new tracks the total safety coefficient shall be at least 1.8.

- Track sections which are exposed to vibration have been taken into account. It has been confirmed that the vibration tolerances are not exceeded in the problematic areas which are already known, and on soft ground which is based on the existing bottom layer research information. Vibration tolerances are presented in RHK's Instruction for Vibration Measurement. The structure has to be strengthened or the traffic has to be limited, if necessary.

Culverts

- All culverts shall be inspected. Damaged and defective culverts are repaired.

Investigations

- A main inspection of culverts, as of bridges, should be made about every 10 years. Not even a careful, well reported walking inspection is alone enough for charting the condition of culverts.

- A study based on the structural calculations and modelling of culverts should ensure that the structures will bear higher axle loads than the present ones.

- The database for culverts and repair instructions should be improved.

- A few long-term fatigue tests corresponding to the cumulative train load of up to 300 million gross tonnage shall be made on frost insulation plates, so that a damage model for frost insulation plates anticipating the effect of the raising of axle loads can be ensured.

- The experiences and expertise from the Joint Nordic Railway Vibration Research Project – NORDVIB shall be utilised.

13.2 300 kN axle loads

On the basis of this investigation it has not been clarified entirely whether an 300 kN axle load is possible. The following section contains measures, pending matters and needs for further investigation:

- The increase of the dynamic wheel load shall be clarified when 300 kN axle loads are used.

- Concrete sleepers shall be redesigned.

- Capacity inspections of bridges shall be made .

- In the designing of new bridges, the α*LM71 load model shall be introduced as soon as possible. In the renovation designing of old bridges the bearing capacity of the bridges should be checked according to the α*LM71 load model.

- One should make additional investigations on switches so that a few switches would be selected which could be followed up for a longer time. All measures, such as e.g. support, measurements and repairs, should be written down during the investigation. The ideal time would be when new switches can be brought to the investigation in the area where the loading is maximum in the present circumstances.

- Resistance to motion, cant (cant excess) and dynamic loads shall be clarified when running on 300 kN axle loads.

- One should make sure, by an investigation based on structural calculations and modelling of culverts, that the bearing capacity of structures is valid for 300 kN axle loads.

- A sufficient embankment width for over 250 kN axle loads should be investigated more closely.

- To define whether the lateral resistance from the ballast bed is sufficient to keep the rail in place while the lateral forces are possibly growing.

- It would be useful to construct a modelling environment which could be used in describing the vertical stiffness of the railway embankment. This would enable anticipation by calculations of the vertical stiffness of the railway embankments, the structure of which is known, among other factors, to contribute towards the stresses on the structural components of the track.

- The measurements made in Koria during the summer of 1999 should be supplemented when the structure is frozen. On the basis of the results it could be evaluated, for instance, how the increasing stiffness due to the freezing of the embankment affects the stresses on track components and the magnitude of the vibration spreading to the track environment.

- One should make provision for winter measurements at the Viiala test culvert site.

- An inspection of train running characteristics, with the help of simulation, could be a necessary further study. The aim is to obtain information especially on the forces affecting the wheel contact.

14. FINAL CONCLUSIONS

On the basis of this investigation the raising of the axle load is possible up to 250 kN at least. The raising of axle loads to 300 kN requires a lot more further investigation and measures, so this will probably be carried out on fairly limited track sections at some point in the future. The most important statements and needs for investigation, resulting from this research project, are presented in the following sections.

14.1 Loads on track structure

- Nowadays the maximum permissible dynamic vertical wheel load (Q) is 170 kN. The maximum permissible dynamic lateral wheel load (Y) is 70 kN. The ratio between the lateral and vertical load, i.e. the so-called derailment criterion, may be 0.8 ($Y/Q \leq 0.8$) at maximum. The dynamic axle load due to 250 kN and 300 kN axle loads cannot in general be determined.

- It is possible to increase axle loads with the new bogies on new generation wagons without essentially increasing dynamic loads on the track.

- The dynamic wheel load depends on the characteristics of the wagon. The wheel load may be influenced by the bogie structure. A 250 kN axle load is permitted in Sweden, if the maximum permissible dynamic vertical wheel load is 170 kN at maximum. The same practice may be followed in Finland as well. The lateral wheel load is not expected to increase when the axle load is raised to 250 kN. It is likely that with 300 kN axle loads the dynamic wheel load will not stay within the permissible 170 kN (Q) and 70 kN (Y) levels.

- The load per metre of wagons cannot be increased with the present track structure. Nowadays 80 kN/metre is permitted.

- The new UIC Leaflet concerning the running behaviour of rolling stock will allow at least 200 kN vertical force instead of the present 170 kN.

14.2 Track and ballast

- It is possible to raise the axle loads to 250 kN on track and ballast, with both 60 E 1 and 54 E 1 rails and continuous welded rails, concrete sleepers on line and concrete or hardwood sleepers in switches, S-type insulated rail joints or an axle counting system, as well as switches with a large radius of curvature.

- The raising of axle loads to 250 kN is partially possible on track sections with 54 E 1 rails and softwood sleepers.

- The raising of the axle load to 250 kN is not possible outside railway yards with 43 kg or lighter rail or jointed rails.

- Fastenings, rail pads or side insulators do not pose any hindrance to the raising of the axle load. Small radii of curvature may only have a bad impact on insulators.

- Sleepers are problematic and thus attention has to be paid to speed limits. Apparently, new sleepers should be designed in a new way.

- In the present railway network the biggest problems would appear even with a 250 kN axle load in the form of the breakage of insulated joints (e.g. Exel), speedy wear of switches (crossings, tongues and bent middle area rail), sinking of base plates into wooden sleepers, changes of gauge in switches, speedy wear of grade 220 (700) rail types, increasing need of maintenance in curve sections, increase in the breaking of aluminothermic welds and breakage of sleepers.

- A growing traffic flow increases the degradation of ballast. Degradation is vigorously increasing, especially in ballast of inferior quality. It is not yet known exactly how significant the raising of the axle load is to the whole process.

- The degradation of railway ballast in a track with concrete sleepers is markedly higher than in a track with wooden sleepers.

- A longer life cycle in the ballast bed is achieved by using high quality ballast, but generally the investment costs then also rise. The strength category for the track section should be chosen by comparing life cycle costs, not on the basis of general rules.

- The raising of axle loads to 250 kN and further up to 300 kN does not significantly increase the degradation of ballast, if the cumulative traffic flow is not increasing and the ballast is firm.

- The raising of axle loads to 300 kN is probably possible on track and ballast with both 60 E 1 rails and continuous welded rails, concrete sleepers on line and concrete or wooden sleepers in switches, S-type insulated rail joints or an axle counting system, as well as switches with a large radius of curvature.

- To define whether the lateral resistance from the ballast bed is sufficient to keep the rail in place while the lateral forces are possibly growing.

14.3 Substructure

- Before the raising of axle loads to 250 kN, switch areas, the rail embankment included, shall be changed in accordance with part 3 “Track structure” of the Technical rules and guidelines for track (RAMO).

- On the basis of the calculation model created the increase of the damage to the frost insulation plate due to the raising of axle loads from 225 kN to 250 kN is 22 – 35 %, depending on the size of the safety factor chosen for the loading of the plate, for instance due to a faulty mounting depth or a dynamic loading. It is possible to prevent the increase of damages by tightening the plate's compression strength requirement to 500 kPa when going over to 250 kN axle loads.

- In the climatic conditions prevalent in the Nordic countries dimensioning of the railway track against frost guarantees that the structural layers of the railway embankment are thick enough for all possible axle loads.

- On the basis of the calculation model created, the increase of the damage to the frost insulation plate due to the raising of axle loads from 225 kN to 300 kN is 82 – 146 %, depending on the size of the safety factor chosen for the loading of the plate, for instance due to a faulty mounting depth or a dynamic loading. It is possible to prevent the increase of damages by tightening the plate's compression strength requirement to 600 kPa when going over to 300 kN axle loads

- According to the present information, the metre load used (120 kN/meter load) when measuring the substructure covers the 300 kN axle loads with two and four axle wagons. It is not possible to raise the metre load on the present track structure.

- An investigation shall be made to reveal whether the embankment width is sufficient for 300 kN axle loads.

14.4 Bridges

- Loads on railway bridges and on similar special structures have been given in Rautatiesiltojen suunnitteluohje (Design Instructions for Railway Bridges), abbreviated to RSO. Loads according to the RSO are also used for designing structures when the distance of the upper surface of a pile slab, a culvert or a corresponding structure is less than 1.4 m from the height level of the track. Loads according to the RSO cover the 250 kN axle loads. Where heavier axle loads are concerned, the load model has to be changed. A new load model (α*LM71) has been created for 300 kN axle loads and this should be used in the planning of new bridges as soon as possible.

- When bridges in poor condition are detected during the main inspection of bridges, there will not be any hindrance to the use of 250 kN axle loads.

- When the capacity of bridges is reviewed using the α*LM71 load model with the partial safety coefficients for load and material according to the present design instructions, it can be seen that 44 % of the bridges on the Rautaruukki - Haparanda line belong to a risk category in which the raising of axle loads up to 300 kN cannot be permitted, 27 % of the bridges should be inspected before the raising of axle loads, and 29 % of bridges do not call for any action at all. According to the total length of bridges on the line, the percentages are correspondingly 16 %, 49 % and 35 %.

- The renewal and repair of bridges will take time, which has to be taken into account when deciding whether 300 kN axle loads are permitted in rolling stock running on the railway network.

- Axle loads have continually been rising throughout the existence of the railway. Making provisions for e.g. 30 % higher axle loads will increase the construction costs by only 3 %. If the traffic management costs during the construction work are taken into account the rise of the overall costs is minor even.

14.5 Stability and vibration

- The load of 120 kN/rail metre is used as a traffic load in track stability calculations. The load is expected to affect the track vertically and impulses are included. According to the existing information the metre load used covers the 300 kN axle loads with two and four axle wagons. It is possible to increase axle loads with the new bogies of new generation wagons without increasing dynamic loads on the track.

- Heavy freight traffic without doubt causes vibration. This fact has also been stated in the Finnish measurements.

- The rise in axle loads, linear density and train length increases vibration. Due to varying local circumstances all research results are not analogous.

- Apart from the features of the rolling stock and embankment, the soil conditions, foundations of buildings and methods of construction, as well as the number of layers and the locations of buildings, affect the local vibration circumstances.

- A piled foundation for railways eliminates vibration almost completely.

- It is usually best to attenuate vibration or prevent the spread of vibration as near to the origin of the vibration as possible.

- When planning to attenuate vibration, one should be extremely familiar with the local circumstances.

- In practice, it is impossible, both technically and economically, to eliminate vibration completely.

14.6 Culverts

- All culverts are different from each other, although a marked regularity among the same type of culverts can be noted.

- It is very difficult or even impossible to make any profound comments on old culverts. It is hard in particular to define the condition of stone culverts lengthened by concrete pipes.

- It is not enough to check the condition of culverts by even a careful, well reported walking inspection only.

- As with bridges, a main inspection should also be made of the culverts every 10 years.

- The database for culverts and repair instructions should be improved.

- One should make sure, by means of an investigation based on structural calculations and modelling of culverts, that the bearing capacity of structures is valid for higher axle loads than the present ones.

- It is extremely difficult to estimate how the raising of the axle load affects the behaviour of even a well-known and documented culvert.

14.7 Statements based on the investigation

- The railway track shall be treated as a common entity where the permanent way and substructure are in balance. In addition, the material of each layer should have the strength and grading properties corresponding to the requirements arising from the raised axle loads.

- The track maintenance costs will rise by less than 5 %, if the highest permitted axle load is raised from 225 kN to 250 kN. In theory, the costs will rise by 5 %, but in reality all axle loads do not reach 225 kN in every axle and besides not all of them will rise to 250 kN. The final number depends on the track section and the axle load distribution.

- The quasi-static modelling of the vertical stiffness of a railway embankment based on the linear elastic layer model corresponds well to the behaviour of the actual railway embankment measured at the instrumentation site. The mechanical behaviour of layer materials and subsoil should however, be described by a model taking the effects of stress level into account. The parameters of the model should be determined in the laboratory with the stress and deformation level corresponding to the real loading conditions.

- Asphalt structures have many advantages, which can be utilised in track structures. They require more study, however, under Finnish conditions.

14.8 Subjects for further studies

- A study shall be carried out to ascertain whether the railway embankment is wide enough for 300 kN axle loads.

- An inspection of train running behaviour with the help of simulation would be a necessary line for further study. In particular, information on the forces affecting the wheel/rail interaction are acquired.

- The increase of the dynamic wheel load when using a 300 kN axle load should be studied.

- The study based on the structural calculations and modelling of culverts should ensure that the structures will bear higher axle loads than the present ones.

- As an addition to the measurements made in Koria during the 1999 summer, it is suggested that another series of measurements be carried out in winter. The railway embankment should be mostly frozen, so that on the basis of the results it could be evaluated, for instance, how the increasing stiffness due to the freezing of the embankment affects the stresses on track components and the magnitude of the vibration spreading to the track environment. One should make reservations for winter measurements at the Viiala test culvert site.

- It would be useful to construct a modelling environment which could be used in describing the vertical stiffness of the railway embankment. This would enable anticipation by calculations of the vertical stiffness of the railway embankments, the structure of which is known, among other factors, to contribute towards the stresses on the structural components of the track.

14.9 Highest permitted speeds and axle loads of different track structures and a suggestion for new track categories

The highest permitted speeds and axle loads have been evaluated for the track structures used. The estimate is based on the bearing calculations and the prevailing practice. The following table also includes speed limits for sidings.

Table 1. Permitted speeds and axle loads for different track structures.

Rail	**Sleepers**	**Rail length**	**Ballast bed**	**Axle load kN / speed km/h**		
				250	**225**	**200**
60 E 1	B88 / B97 / BP 89 / BP 99	CWR	Railway ballast	100	140	200
54 E 1	B86 / B97 / BP 89 / BP 99	CWR	Railway ballast	80	120	160
54 E 1	B86 / B97 / BP 89 / BP 99	Jointed track	Railway ballast	30	100	120
54 E 1	B75 and older concrete sleepers	CWR	Railway ballast	60	100	120
54 E 1	Wooden sleepers	CWR	Railway ballast	60	100	120
54 E 1	Wooden sleepers	Jointed track	Railway ballast	30	100	120
54 E 1	Wooden sleepers	Jointed track	Gravel	20	60	80
K43	All sleepers	Jointed track	Railway ballast	20	80	90
K43	Wooden sleepers	Jointed track	Gravel	10	50	60

CWR = continuous welded rails

The new proposed track categories, corresponding to the above, are presented in table 2.

Suggestion for track categories in the Technical Specifications and Rules which pertain to Train Safety Regulations (Jtt)

The track categories in the publication Technical Specifications and Rules which pertain to Train Safety Regulations (Jtt) could be in line with table 2 after the introduction of 250 kN axle loads. A map showing how the track sections are divided into different track categories is shown in figure 1.

In accordance with the superstructure the track sections C_2 or D should belong to track category C_1 until the 250 kN axle load has been introduced on the track section in question.

Table 2. Suggestion for track categories

Track category	Rails	Sleepers	Ballast bed	Speed [km/h]	Axle load[1)] [kN]	Regarding
A	K30	Wooden, concrete	Gravel, railway ballast	(90)	(100)	Passenger trains
				70	160	Passenger trains
				50	160	Freight trains
				40	200	Freight trains
B_1	K43, K60 54 E 1	Wooden, concrete	Gravel	100	160	All trains
				60	200	Freight trains
				50	225	Freight trains
B_2	K43, K60	Wooden, concrete	Railway ballast	110	160	All trains
				90	200	Freight trains
				80	225	Freight trains
C_1	54 E 1	Wooden, Concrete < B86	Railway ballast	160[2)]	160	Passenger trains
				180[3)]	160	Passenger trains
				120	200	Freight trains
				100	225	Freight trains
				60	250	Freight trains
C_2	54 E 1 CWR	Concrete ≥ B86 hardwood	Railway ballast	200	160	Passenger trains
				160	200	Freight trains
				120	225	Freight trains
				80	250	Freight trains
D	60 E 1 CWR	Concrete	Railway ballast	220	180	Passenger trains
				160	200	Freight trains
				140	225	Freight trains
				100	250	Freight trains
				(60)	(270)	Freight trains

1) Does not concern locomotives in a train
2) Wooden sleepers, over 120 km/h CWR (continuous welded rail)
3) Concrete sleepers, over 120 km/h CWR

Track class	Non elect-rified	Elect-rified	Rails	Slee-pers	Ballast
A			K30, K33	wooden, concrete	gravel or equal
B_1			K43, K60 54 E 1	wooden, concrete	gravel or equal
B_2			K43, K60	wooden, concrete	railway ballast
C_1			54E1	wooden, concrete (B< 86)	railway ballast
C_2			54E1	concrete (B≥86)	railway ballast
D			60E1	concrete	railway ballast

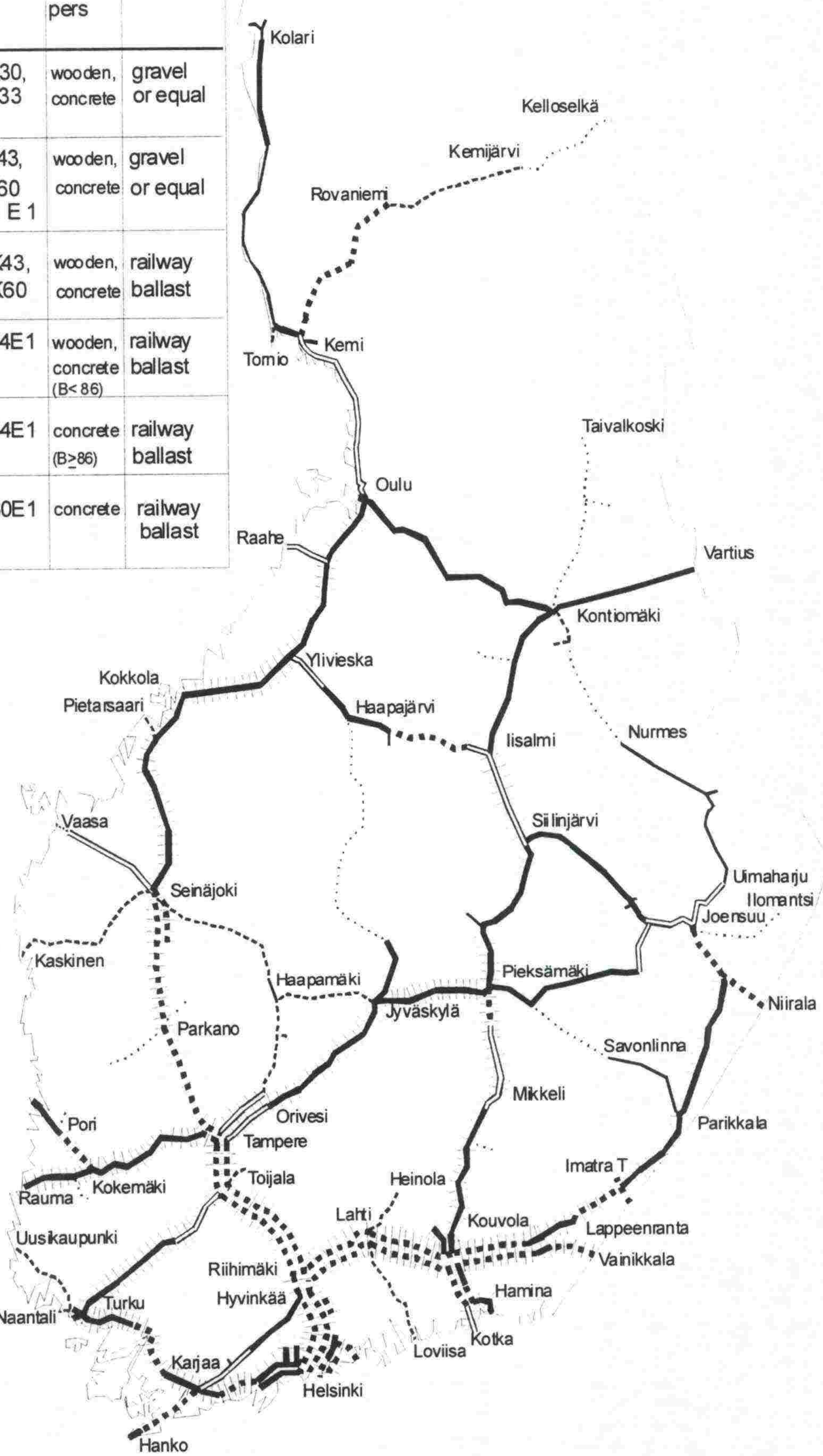

Figure 1. Suggestion for new track categories when introducing a 250 kN axle load

FINNISH RAIL ADMINISTRATION'S PUBLICATIONS REGARDING THE AXLE LOAD PROJECT

Publications in Finnish language (a summary in English language included)

A 1/1999	Literature study of the instrumentation of rail structure, 250 kN and 300 kN axle loads
A 3/1999	Railway traffic induced ground vibration, 250 kN and 300 kN axle loads
A 4/1999	Plan for instrumentation and modelling a railway track, 250 kN and 300 kN axle loads
A 5/1999	Vibration measuring practice in the Nordic countries
A 6/1999	Literary research of ballast and substructure, 250 kN and 300 kN axle loads
A 7/1999	Classification and inventory of railway bridges on the Rautaruukki – Haparanda line section to increase allowable axle loads
A 8/1999	Field study on culverts, 250 kN and 300 kN axle loads
A 3/2000	Literary research on rolling stock, 250 kN and 300 kN axle loads
A 4/2000	Effects of strength on the life cycle of railway ballast
A 5/2000	Instrumentation and modelling of track structure, 250 kN and 300 kN axle loads
A 6/2000	Intermediate Report, 250 kN and 300 kN axle loads
A 2/2001	XPS Frost Insulation Plates in track structure, 250 kN and 300 kN axle loads
A 3/2001	Railway Track Study, 250 kN and 300 kN axle loads
A 4/2001	Literature study on the track maintenance costs, 250 kN and 300 kN axle loads
A 5/2001	Final Report, 250 kN and 300 kN axle loads

Publications in English language

A 6/2001	Final Report, 250 kN and 300 kN axle loads
A 7/2000	Intermediate Report, 250 kN and 300 kN axle loads
A 10/2000	Instrumentation and modelling of track structure, 250 kN and 300 kN axle loads

Publication in Swedish language

A 2/2000	Bantrummor, 250 kN och 300 kN axellaster

Publications of the Finnish Rail Administration A

1/1997	Railway Industry Structures and Capital Investment Financing
2/1997	Nopean junaliikenteen aluekehitysvaikutukset
3/1997	Rautateiden henkilöliikenteen ennustemalli (RALVI)
4/1997	Kilpailuedellytykset ja niiden luominen Suomen rataverkolla
5/1997	Rataverkon tavaraliikenne-ennuste 2020
1/1998	Rataverkon jatkosähköistyksen yhteiskuntataloudellinen vaikutusselvitys
2/1998	Suomen rautatieliikenteen päästöjen laskentajärjestelmä (RAILI 96)
3/1998	Rautateiden tavarakuljetusten laatutekijät
4/1998	Ratahallintokeskuksen tutkimus- ja kehittämistoiminta 1997 - 99
5/1998	Rataverkon kehittämisen yhdyskuntarakenteellisten vaikutusten ja menetelmien arviointi
6/1998	Yksityisrahoituksen käyttömahdollisuudet Suomen ratahankkeissa
1/1999	Ratarakenteen instrumentoinnin kirjallisuustutkimus, 250 kN:n ja 300 kN:n akselipainot
2/1999	Rautatieliikenteen polttoaineperäisten päästöjen aiheuttamat ympäristökustannukset
3/1999	Rautatieliikenteen aiheuttama tärinä, 250 kN:n ja 300 kN:n akselipainot
4/1999	Ratarakenteen instrumentointi- ja mallinnussuunnitelma, 250 kN:n ja 300 kN:n akselipainot
5/1999	Rautatietärinän mittauskäytäntö Pohjoismaissa
6/1999	Radan tukikerroksen ja alusrakenteen kirjallisuustutkimus, 250 kN:n ja 300 kN:n akselipainot
7/1999	Rautatiesiltojen luokittelu ja inventointi rataosuudella Rautaruukki–Haaparanta akselipainojen korottamista varten
8/1999	Ratarumpujen maastoselvitys, 250 kN:n ja 300 kN:n akselipainot
1/2000	Rataverkko 2020 -ohjelman väliraportti. Kehittämisvaihtoehtojen vaikutustarkastelut
2/2000	Bantrummor, 250 kN och 300 kN axellaster
3/2000	Liikkuvan kaluston kirjallisuustutkimus
4/2000	Raidesepelin lujuuden vaikutus tukikerroksen ikään
5/2000	Ratarakenteen instrumentointi ja mallinnus, 250 kN:n ja 300 kN:n akselipainot
6/2000	Väliraportti 250 kN:n ja 300 kN:n akselipainojen ratateknisistä tutkimuksista
7/2000	Intermediate Report, 250 kN and 300 kN axle loads
8/2000	Ratatekniset määräykset ja ohjeet -julkaisun käytettävyystutkimus
9/2000	Ratakapasiteetin perusteet
10/2000	Instrumentation and Modelling of Track Structure, 250 kN and 300 kN axle lo
11/2000	Rautatieonnettomuuksien sisäiset ja ulkoiset kustannukset
12/2000	Internal and External Costs of Railway Accidents
1/2001	Rataverkko 2020 -suunnitelma
2/2001	XPS-routaeristelevyt ratarakenteessa, 250 kN:n ja 300 kN:n akselipainot
3/2001	Raidetutkimus, 250 kN:n ja 300 kN:n akselipainot
4/2001	Radan kunnossapitokustannukset, 250 kN:n ja 300 kN:n akselipainot
5/2001	Loppuraportti 250 kN:n ja 300 kN:n akselipainojen teknisistä tutkimuksista

FINNISH RAIL ADMINISTRATION TECHNICAL UNIT
KAIVOKATU 6, P.O. Box 185
FIN-00101 HELSINKI

For further information, please contact:
Mr. Kari Ojanperä, Tel. +358 9 5840 5183, e-mail: kari.ojanpera@rhk.fi
Mrs. Sinikka Kiikka, Tel. +358 9 5840 5192, e-mail: sinikka.kiikka@rhk.fi

ISBN 952-445-052-6
ISSN 1455-2604