
INTERMEDIATE REPORT

250 kN AND 300 kN AXLE LOADS

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SUMMARY

This intermediate report forms part of the Finnish Rail Administration's research work with the aim of introducing 250 kN and 300 kN axle loads. The study began in the summer of 1998. The report has been compiled by the Laboratory of Highway Engineering at the Helsinki University of Technology (TKK/TIE) in Otaniemi.

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. The report is based on the earlier published research reports and interviews with experts.

Loads on track structure

Nowadays the maximum permissible dynamic vertical wheel load (Q) is 170 kN. The dynamic vertical load is expected to vary on a track in good condition as the coefficient of static load between 1,5 x axle load ($V < 60$ km/h) ... 2 x axle load ($V=250$ km/h). 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.

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 maximum 170 kN. 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.

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 300 kN or heavier axle loads are concerned, the load model has to be changed. A planned load model for an axle load of 300 kN in this report is referred to as "RHK-2000".

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. The load is

fatiguing and dynamic. When designing pile foundations the lateral loads due to earth pressure also have to be taken into consideration. According to the existing information the metre load used covers the 300 kN axle loads.

Common statements based on the research

- Heavy freight traffic without doubt causes vibration. This fact has also been stated in the Finnish measurements. The general opinion is that the raising of the axle loads increases vibration.
- In practice it is impossible, both economically and technically, to eliminate vibration completely.
- The vibration of tracks built on soft ground increases as the linear density grows.
- 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.
- Asphalt structures in tracks have many advantages. They require more study, however, in the Finnish climate. In particular, the effects of the winter are not well enough known.
- All culverts are similar, although a marked regularity among the same type of culverts is observable.
- It is very difficult or even impossible to make any profound comments on old culverts. In particular it is difficult to specify the condition of stone culverts lengthened by concrete pipes.
- 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 material 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 actual loading conditions.

Statements based on a study on the implementation of a 250 kN axle load

- 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, each layer material should have the strength and grading properties which correspond with the requirements arising from the increased axle loads.

- It is extremely difficult to estimate how the raising of the axle load affects the behaviour of even a well-known and documented culvert.
- The frost insulation plates used may not necessarily bear even the present axle loads without breaking and becoming moist. However, the 19 year-old plates were by no means in such a bad condition as was suspected, but rather vice versa. The double layer structure and sand isolation maintain the insulation capacity of the plates well.
- If bridges in poor condition are detected in association with the main supervision of bridges, there is no hindrance to the use of 250 kN axle loads.
- None of our own tests on the impact of raising axle loads on the degradation of ballast have been carried out. 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 in the USA 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.
- There are no research results available on the impact of raising axle loads from 225 kN up to 250 kN on a ballast bed, but on the basis of the above-mentioned 300 - 350 kN it can be assumed that the increase will not significantly affect the degradation of ballast.
- It is possible to increase axle loads with the new bogies of new generation wagons without increasing dynamic loads on the track.

Statements based on a study on the implementation of a 300 kN axle load

- When the capacity of bridges is reviewed using the load model RHK-2000 with the partial safety coefficients for load and material according to the present design instructions, 44 % of the railway bridges on the track section between Rautaruukki and Haparanda (Sweden) belong to the risk category in which the raising of the axle load up to 300 kN cannot be permitted, 27 % of the railway bridges need to be inspected before the raising of the axle load, and 29 % of railway bridges do not require any action. Divided according to the total bridge length on the track section, the percentages are 16 %, 49 % and 35 %.
- Renewal and repair of bridges take time, a factor needing be taken into account when deciding whether 300 kN is permitted for rolling stock running on the railway network.
- Axle loads have been constantly increasing during the time the railways have existed. Provision for e.g. 30 % heavier axle loads increases the construction costs of a bridge by only 3 %. If the traffic management costs are taken into account during the construction, the increase in the total costs is even smaller than this.
- Dimensioning of frost insulation corresponding to Nordic conditions guarantees a sufficient thickness of substructure layers for all conceivable axle loads.

Further actions concerning the implementation of 250 kN and 300 kN axle loads

- In the designing of bridges, the load model RHK-2000 should 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 load model RHK-2000.
- To define how much the dynamic wheel load increases while using 300 kN.
- 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.
- On the basis of the modelling work done thus far it seems to be possible 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 handling of measuring results obtained by a so-called diagnostic train could be an interesting field of application for the aforementioned modelling environment of the vertical stiffness of the railway structure .
- A more detailed study into whether the embankments are wide enough ought to be undertaken, because compared to several other countries the railway embankments in Finland are relatively narrow.
- The studies on whether the embankment width is sufficient are suggested to be continued, initially by theoretical studies based on the use of more sophisticated modelling tools - primarily the use of the finite element method.
- As an addition to the measurements made in Korja during the 1999 summer, another series of measurements is suggested to be carried out during the early spring of 2000. 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. Winter measurements would also give a more reliable basis for isolating the deformation in the subsoil from the overall changes taking place in the railway embankment detected in the measurements during the 1999 summer. (The measurements were cancelled because of the mild winter.)
- The results of the theoretical modelling could be applied to the planning of a separate instrumentation site which would serve in the verification of the impact of the embankment width. This cannot be carried out, however, before the 2001 summer.
- Not even a careful, well reported walking inspection is alone enough for charting the condition of culverts. A main inspection of culverts, as of bridges, should be made about every 10 years. The database for culverts and repair instructions should be improved.
- The study based on the structural calculations and modelling of culverts should

ensure that the structures will bear 250 kN and 300 kN axle loads.

- An inspection of train running characteristics, with the help of simulation, could be a necessary further study. The aim is to obtain information on the forces affecting the wheel contact. The best way to start is to become acquainted with the Swedish simulation studies.

Ongoing studies:

- A degradation of ballast study will be made by the Tampere University of Technology (TTKK/RGL).
- Further study on instrumentation. Measurements in Koria are planned to continue in March. Vibration will also be measured. (Cancelled because of the mild winter.)
- A four-month-long literary study and interviews on the track was launched in January 2000. The study covers rails, rail fastenings and sleepers.
- Study on culverts. Cooperation with Swedish experts is commencing.
- Maintenance and maintenance costs. Technical and economical study is important. By how much are the maintenance costs changing while axle loads are rising?
- "Joint Nordic Railway Vibration Research Project - NORDVIB". The railway traffic induced ground vibration.

Future studies:

- The issues to be investigated in the study on the resistance to motion and canting on the rail would probably be resistance to motion, canting on rail (negative side acceleration) and dynamic loads with 300 kN axle loads.
- Surveys concerning the instruction for the capacity inspection of bridges.
- Switches and crossings.
- Study on frost insulation plates.
- Asphalt on superstructures.
- Final report. Going through the results of the research work and comparing these with the present norms.

FOREWORD

This intermediate report has been compiled by the Laboratory of Highway Engineering at the Helsinki University of Technology (TKK/TIE) in Otaniemi, Espoo. The report forms part of the Finnish Rail Administration's research with the aim of introducing 250 kN and 300 kN axle loads. The research was started in the summer of 1998. The results of the study are briefly covered in the report. Suggestions for further investigation and measures brought about by the different studies are also presented. The report is based on previously published research reports and interviews with experts.

The report has been compiled by Jarkko Valtonen and Matti Levomäki from the Laboratory of Highway Engineering at the Helsinki University of Technology. The work has been supervised by Pasi Leimi from the Finnish Rail Administration. The whole research work has been supervised by a steering group composed of the following members: Markku Nummelin, Pasi Leimi and Kari Ojanperä from the Finnish Rail Administration, Technical Unit, Olli-Pekka Hartikainen, Jarkko Valtonen, Matti Levomäki and Iikka Järvenpää from the Helsinki University of Technology, Raimo Uusinoka and Pauli Kolisoja from the Tampere University of Technology, and Seppo Kähkönen from ANSERI-Konsultit Oy.

Helsinki, July 2000

Finnish Rail Administration
Technical Unit

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1. 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.

Publications to be included in the list were not only found in the files of the Finnish Rail Administration (RHK), but also on the book shelves of experts, at VR-Track Ltd, at the Tampere University of Technology (TTKK) and the Helsinki University of Technology (TKK), as well as through the Internet. 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 publications, memos, standards, research results, seminar reports, articles and other written material which is 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. This list can best be used in an electronic form, and it is being updated in conjunction with the research work in order to cover those publications which are found later on as well. 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.

The research work was undertaken by the Laboratory of Highway Engineering at the Helsinki University of Technology. Report A 1/1999 (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.**

2. RAILWAY TRAFFIC INDUCED GROUND VIBRATION

The literature study concerning railway traffic induced ground vibration consists of a short presentation of the origin and drift of vibration. 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. Domestic and foreign literature, research reports ordered previously by VR and the Finnish Rail Administration, as well as interviews made in this connection, have been used as the source material.

The study was made in the Laboratory of Highway Engineering at the Helsinki University of Technology. 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.**

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

- The vibration of tracks which have been founded on soft ground increases as trains become longer.
- There are no research results available on the impact of heavier axle loads on the origin of vibration. It is generally agreed that the rise in axle loads increases vibration, but all research results are not analogous.
- Apart from the features of rolling stock and embankment, the soil conditions, foundations of buildings and methods of construction, as well as the materials, number of layers and the locations of buildings, affect the local vibration circumstances.
- Methods of construction, materials and location of buildings seem to have a much stronger impact on vibration than the foundation. The piled foundation is an exception to this.
- A piled foundation of railways eliminates vibration almost completely. On the other hand, a piled foundation causes a risk of the horizontal movement of the foundation in certain situations.
- 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.

In connection with the instrumentation of the railway structure, vibration measurements were carried out on the Kouvola - Korja line in the 1999 summer. Vibration measurements will be continued in the spring of 2000. The "Joint Nordic Railway Vibration Research Project - NORDVIB" will be launched. In all cases railway traffic induced ground vibration has to be studied from the environmental viewpoint.

3. CLASSIFICATION AND INVENTORY OF RAILWAY BRIDGES ON THE RAUTARUUKKI - HAPARANDA LINE TO INCREASE PERMITTED AXLE LOADS

3.1 Summary

A preliminary study on the capacity of bridges on the Rautaruukki - Haparanda line (total 145 bridges) has been made on the basis of the main drawings and calculations for several bridges. The load model RHK-2000, in addition to the partial safety coefficients for the load and material of the present design instructions, have been used in the study. An investigation has been made as to whether the permitted axle load can be raised from the present 225 kN to 250 kN, or even up to 300 kN. The investigation was carried out in the Laboratory of Bridge Engineering at the Helsinki University of Technology. 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 Rautaruukki - Haparanda Line to Increase Permitted Axle Loads.**

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. With the help of the inspection for 300 kN axle loads the bridges have been divided into risk categories according to which some criteria for repair, maintenance and renewal procedures of different levels have been found. The new load model RHK-2000 should be used in the planning as soon as possible.

When the capacity of bridges is reviewed using the load model RHK-2000 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 %.

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 railway bridges belong to a risk category where the raising of the axle loads up to 300 kN cannot be permitted, 55 % of railway bridges should be inspected before the raising of axle loads and 25 % of railway bridges do not need any action at all.

3.2 Common criteria, measures and observations

If there are no calculations on substructures, 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 the traffic flow of 19 million gross tons/track/year for the specific trains in 1975 - 2000. The gross tonnages on this line are considerably minor. 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 in 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*. As to 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 a preliminary weakening in 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 and renewal of old bridges and the planning of new bridges the load model RHK-2000 should be introduced as soon as possible. In the repair design the capacity of old bridges should be inspected for the load model RHK-2000. 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. 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.

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

- The crossbars in old steel bridges and secondary longitudinal grinders, which have had a high number of load cycles during their lifetime.
- Old slab portal bridges with one opening; the structures may need some enforcement.
- 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 RHK-2000):

- A concrete steel bridge with 1 opening, which is measured in accordance with I-48 or an older load model and with a span of less than 15 m.
- A steel bridge with 1 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 1 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 1 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 concrete steel 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 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 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.

3.3 Further measures

The inspection shows that 250 kN can fairly well be used on bridges on the Rautaruukki - Haparanda line. Before 300 kN axle loads can be used in trains, more precise inspections and calculations should be made on the bridges. In order to make these, there should exist calculation instructions by 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 measurements of the structures
- more precise calculations as to bearing capacity
- fatigue inspections and evaluating the remaining lifetime.

The impact of the impulse ratio is important in the design load. By improving the quality of 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 rail can be improved by a cast damping layer between the steel structure and the sleeper. In old steel bridges especially the capacity of secondary structures can be improved in this way. This technique should be developed.

4. ROLLING STOCK

The literary research on rolling stock was made in the Laboratory of Automotive Engineering at the Helsinki University of Technology in 1999. 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**. How the eventual raising of axle loads affects the dynamic loads caused by rolling stock and the rolling stock itself was studied in conjunction with the literary study.

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 of track stiffness in the vertical direction. There are two main types in 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 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 points, 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 finish has proved to be a good method according to Swedish experiences.

The impact of improved 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 Swedish simulation studies.

5. BALLAST AND SUBSTRUCTURE

The literary study on ballast and substructure was made in cooperation with the laboratories of Geotechnical Engineering (TTKK/GEO) and Engineering Geology (TTKK/RGL) at the Tampere University of Technology and the Laboratory of Highway Engineering at the Helsinki University of Technology (TTK/TIE). 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**. A master's thesis (TTKK/RGL) on ballast has also been completed in February 2000. 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**.

The aim of the literary study was to summarise the effects the raising of axle loads would have on ballast bed and substructure. The basis of the research was the material which was collected during the literary survey commissioned by the Finnish Rail Administration. In the master's thesis the aim, based on literary and own test results, is to estimate the quality of the most favourable railway ballast with respect to life cycle and investment costs.

Principle issues to be investigated in the ballast bed were the effects of the increased axle loads on the quality requirements of railway ballast and the requirements for dimensions of the ballast bed. 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 possibilities of using asphalt materials in railway structures were also studied.

The following can be stated as conclusions of the whole literary study and the master's thesis:

- The degradation of ballast can be decreased by the following methods:
 - Stroking stress on ballast bed which arises in rail joints, bad welding joints, on an uneven rail, in damaged track parts and by worn wheels, should be minimised.
 - Support should be minimised. The sinking of embankment and subsoil should be minimised and thus the need to tamp down.
 - The content of the fouling 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.
 - Wooden sleepers must be used.
 - A stiff 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 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, not on the basis of general rules.
- 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.
- None of our own tests on the impact of raising axle loads on the degradation of ballast have been carried out. 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 in the USA 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.
- There are no research results available on the impact on the ballast bed of raising axle loads from 225 kN to 250 kN, but on the basis of the above-mentioned 300 – 350 kN it can be assumed that the increase will not significantly affect the degradation of ballast.
- 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, each layer material 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 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 these parts of the railway track.
- 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 other hand, we should more closely study whether the embankments are wide enough, because compared to several other countries they are relatively narrow in Finland.
- Extruded Polystyrene (XPS) frost insulation products should be tested according to the present CEN-standards. In practice, the correlation between the static

compression strength of XPS frost insulation products and the permitted amount of load cycles can only be determined by means of laboratory tests.

- Asphalt track structures have many advantages. They require, however, more study in the Finnish climate. In particular, the effects of the winter 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 - the finite element method (FEM) in the first place - 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.

6. CULVERTS

The study on culverts was made in the Laboratory of Highway Engineering at the Helsinki University of Technology. Report A 8/1999 (ISBN 952-445-027-5, ISSN 1455-2604, 27 pages) was published by the Finnish Rail Administration under the title: **Culvert Study, 250 kN and 300 kN axle loads**. The study was carried out so that culverts were listed according to the culvert registers from the Oulu and Kemi regional offices. After that, some culverts were studied in the field on the line between Raahe and Tornio.

It can be said, on the basis of the study, that heavy axle loads have the following effects on 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.
- 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 culverts.
- In some places concrete structures were in a fairly bad condition.
- It is difficult to estimate the condition of the inner parts of the lengthened culverts.
- 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 necessarily particularly accurate. 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 influences heavy axle loads have even on well documented culverts

The line between Tornio and Raahe:

- If heavier axle loads are sometimes going to be used on the line between Tornio and Raahe, all 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 repair planning of culverts should be improved. One should make sure, by an investigation based on structural calculations and modelling of culverts, that the bearing capacity of structures is valid for 250 kN and 300 kN axle loads.

General further measures can be listed as follows:

- A general study on the structure of culverts, their lengthening techniques and the most common forms of damage and repair methods.
- Cooperation with Banverket (Sweden), TTKK and LTH (Luleå University of Technology) and possibly with Jernbaneverket (Norway) in order to improve culvert structures and measurements.
 - Studies on the present measuring methods for culverts
 - Test building
 - measurements on temporary loading
 - long-term deformation measurements (period of 3 - 4 years).
- Analysing of measuring results and improvement and comparison of calculation methods
 - Recommendations on the structural requirements for culverts and the measuring methods.
- General specification and quality requirements for a culvert.

7. INSTRUMENTATION AND MODELLING

A plan for the instrumentation and modelling of a railway track was drafted in cooperation with the Laboratory of Geotechnical Engineering at the Tampere University of Technology (TTKK/GEO), and the laboratories of Mechanics of Materials (TKK/LUJ) and Highway Engineering (TKK/TIE) at the Helsinki University of Technology. 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 plan contains the instrumentation methods for track structure, the work phases, costs and the handling of results on the line between Kouvola and Korja, at a distance of 187 km +580 m from Helsinki, which were carried out in the 1999 summer.

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 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 railway track, 250 kN and 300 kN axle loads.**

Conclusions

Generally the results and the analyses of the measurements made at the Korja instrumentation site can be considered to confirm the conclusions made 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 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.
- It is clearly more difficult to specify a sufficient width of railway embankment in regard to stability corresponding to different size axle loads in long-term repeated loading than 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 in the instrumentation site provide a clear indication that in certain parts of the railway embankment there will be horizontal cyclical tensile strains with high axle loads. The larger 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.

Needs for further investigations

The following can be said of the application of modelling work which describe the mechanical function of the railway embankment and the needs 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 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 in the layers, as well as the type of the 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.
- An interesting field of application for the modelling environment of the stiffness of the railway structure would be to combine it with the handling of the measuring results on the so-called diagnostic train. Then the modelling environment would in principle act as a tool in the interpretation of measuring results related to extensive investments in the railway network and in analysing the operation and repair alternatives of single problem areas.
- The studies on whether the embankment width is sufficient are suggested to 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 try 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. This could be accomplished in the summer of 2001 at the earliest.
- As an addition to the measurements made in Korja during the 1999 summer, another series of measurements is suggested to be carried out during the early spring of 2000. 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. 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 should be rebuilt, but the instrumentation can be carried out in a somewhat simpler way than in the 1999 summer. (This was cancelled due to the mild winter.)

8. FROST INSULATION PLATES

8.1 Prestudy on frost insulation plates

The study on frost insulation plates was made in the Laboratory of Highway Engineering at the Helsinki University of Technology in the summer of 1999. The frost insulation report will not be published. The study involved digging out samples from frost insulation plates and ballast at Turenki railway yard. The position of frost insulation plates was also investigated together with VR-Track Ltd.

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:

- The frost insulation plates used may not necessarily bear even the present axle loads without becoming broken or moist.
- The method of installation and installation materials do apparently affect the durability of the plate surface rather a lot. Under heavier axle loads the surface of a plate is damaged more quickly.
- Ballast degradation gathers moisture on top of the plates.
- The use of frost insulation plates and whether their use is sensible should be investigated by further studies.
- Samples of frost insulation plates can be taken manually. This takes two people 1 - 1.5 h per sample .

8.2 Appendix to the prestudy on frost insulation plates

The study on frost insulation plates was continued in the autumn of 1999. Samples were taken in Siilinjärvi and Inkeroinen. The further study was reported as an appendix to the prestudy. Some observations from the further study are as follows:

- When two plates are installed on top of each other, the lower one will more certainly remain undamaged and it can be assumed that the thermal insulation will remain better compared to the situation when only one thicker plate is installed. In Siilinjärvi especially two plates were installed on top of each other, although according to some previous information there were supposed to be only single-layer plates.
- The plates in Inkeroinen had been installed lower than expected. This was due to the fact that the switch points were so near. As a consequence, the samples from Inkeroinen are not compatible with those on other samples. The plates which were installed in the lowest parts (90 cm under height level) were the least damaged.
- It is noteworthy that even within the course of one year the surface of plates may become damaged and water can penetrate into the plate. It is clear that the thermal insulation of a plate is then not as efficient as with the original one.
- 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.

- The taking of samples in Siilinjärvi went well as the ballast was finer than in other places.

There are many variables associated with an inspection of frost insulation plates:

- the type of plate
- thickness
- one or two layers
- installation depth and
- protection.

With only a few samples it is not possible to obtain any reliable information on the present situation with respect to frost insulation plates. Sampling methods should be improved.

8.3 The investigation on the condition of the existing frost insulation plates

The investigation on the condition of the existing frost insulation plates will be continued by investigating frost insulation plates of different ages and from different manufacturers.

8.4 New frost insulation plates

Theoretical and experimental studies are required by new frost insulation plates in the technical specifications.

- The durability of materials to the fatigue cyclic loading should be tested at different loading and deformation levels in controlled laboratory conditions. The aim is to specify the dependency of cyclic loading and the permitted number of load repetitions corresponding to different irreversible deformation levels.
- As it is not necessarily appropriate or possible to make very long-term cyclic loading tests during routine quality control, the connection of the ability to withstand/resist cyclic loading and the static compressive strength of the frost insulation plate should be verified. The testing method would comprise static compression tests made for the frost insulation plate material tested in the cyclic loading mentioned in the previous chapter.
- The vulnerability of frost insulation plates, which are installed directly under the ballast bed during ballast cleaning should be tested by means of loading in which the load directed at a frost insulation plate sunk in water is transmitted on top of the plate through a rough ballast layer. With the same test arrangements the impact and effect of the surface finishing of the plates - e.g. laminating by a geotextile or other reinforcing material on top of the plate - could be tested.
- Another subject probably to be tested more closely is the dynamic behaviour of frost insulation plates, especially under high-speed traffic. With a too flexible material there might be a risk of dangerous resonance vibration of the upper part of embankment, if the natural frequency of the upper part of the embankment begins to approach close to the frequency of the loading. This problem could be analysed by

modelling the dynamic behaviour of the upper part of the embankment. The initial data, i.e. the required characteristics of frost insulation plates, could be mainly obtained from the previously mentioned laboratory tests. The dynamic characteristics of the layer materials needed in the analysis can be defined by using the relevant laboratory investigation methods.

9. JOURNEYS

9.1 Russia

Seppo Kähkönen from ANSERI-Konsultit Oy and Vladimir Segercrantz from the Technical Research Centre of Finland, Communities and Infrastructure (VTT/YKI) acquainted themselves with the axle loads used in the Russian railways and their future plans. The travel report was published as a publication of the Technical Research Centre of Finland (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 even catastrophic, especially for over 3 metre-high embankments. Bridges caused some trouble as well.

In 1999, the maximum permitted axle load for freight wagons is 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.

9.2 Sweden

Luleå

A visit to Luleå was made in connection with the research project. Representatives from the Finnish Rail Administration, as well as the Helsinki and Tampere Universities of Technology, participated. Apart from creating new contacts the main interest was focused on the investigations made by 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:

There are a total of 800 culverts on the iron ore line. Five of these were damaged during the first test run of 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 SEK 100 million.

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 made longer.

Concrete gravel is local and fairly good in quality but slightly varying (by visual estimate 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 borders 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 are affecting 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, although the Russian axle load is 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 1995. Banverket has invested SEK 140 million annually in the ore line. SEK 30 million of this has been spent on rails. MTAB (the iron ore company) has invested SEK 40 million 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 in Luleå. The planned 300 kN axle load 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 minus 30 %, if the axle loads are increased to 300 kN. A heavier axle load decreases gross register tonnage, i.e. the relative share of wagons in the mass is decreasing.

Stockholm and Gothenburg

An interview in Stockholm at the Royal University of Technology was carried out in connection with the research project. The aim of the trip was to become acquainted with, and to interview, experts on vibration and to obtain information on the items 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.

- 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 vaikutus selvitys
 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 värinä, 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 Rautaruuki-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

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