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ROADEX road design method

ROADEX IV final seminar
Inverness, 21 May 2012

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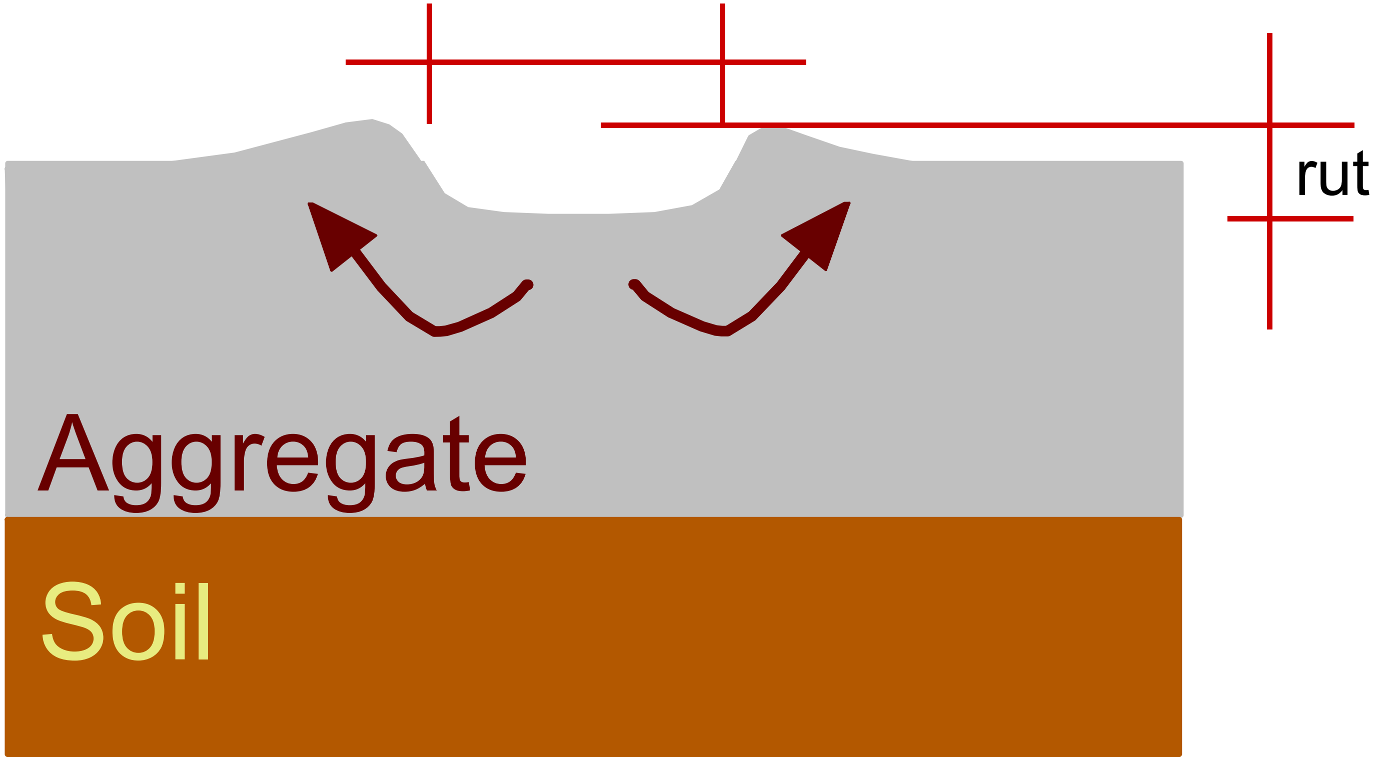
Outline of the presentation

- ROADEX definition of rutting modes
- Principle of the design approach for Mode 1 rutting
- Principle of the design approach for Mode 2 rutting
- Determination of design parameters
- Permanent deformation demonstrations sites in Jämsä, Central Finland
- Summary

ROADEX definition of rutting modes

Mode 0 rutting

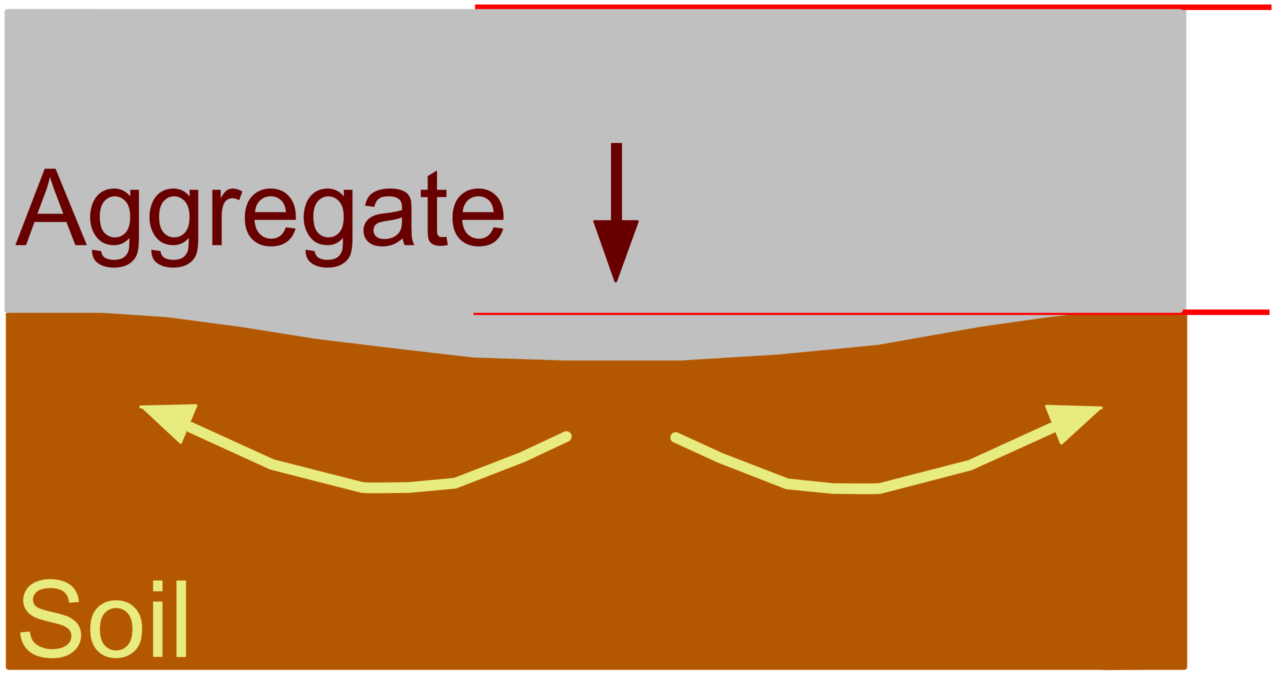
ROADEX definition of rutting modes



Mode 1 rutting

Mode 1 rutting in base course

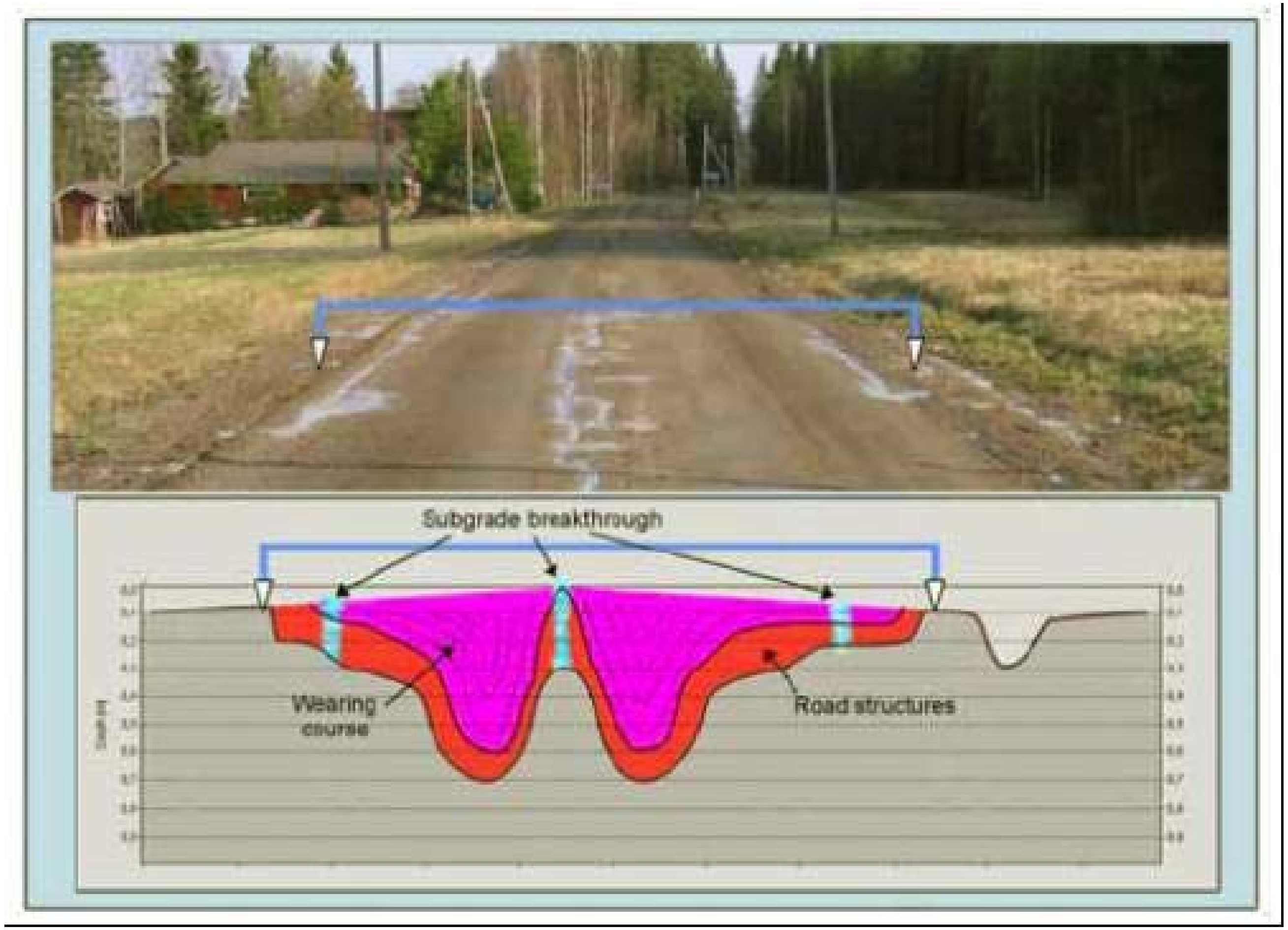
ROADEX definition of rutting modes



Mode 2 rutting

Severe mode 2 rutting in the subgrade

Typical mode 2 rutting problem in the seasonal frost areas



ROADEX definition of rutting modes

We can define three modes of rutting, depending on how and where the plastic strain accumulates

- Mode 0 = Compaction strain in upper layers
- Mode 1 = Shear strains in the near-surface layers
- Mode 2 = Shear strains in deeper layers (especially the subgrade)

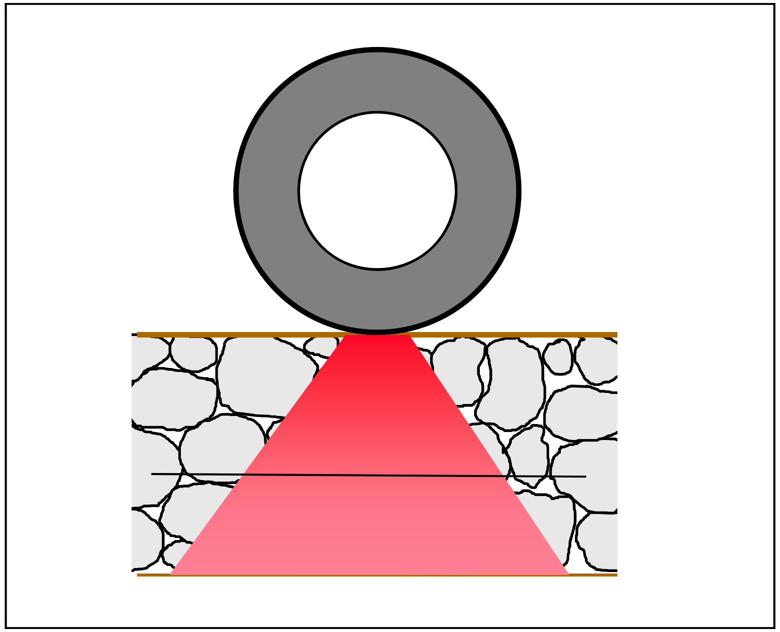
Basic solutions to Mode 1 rutting problem

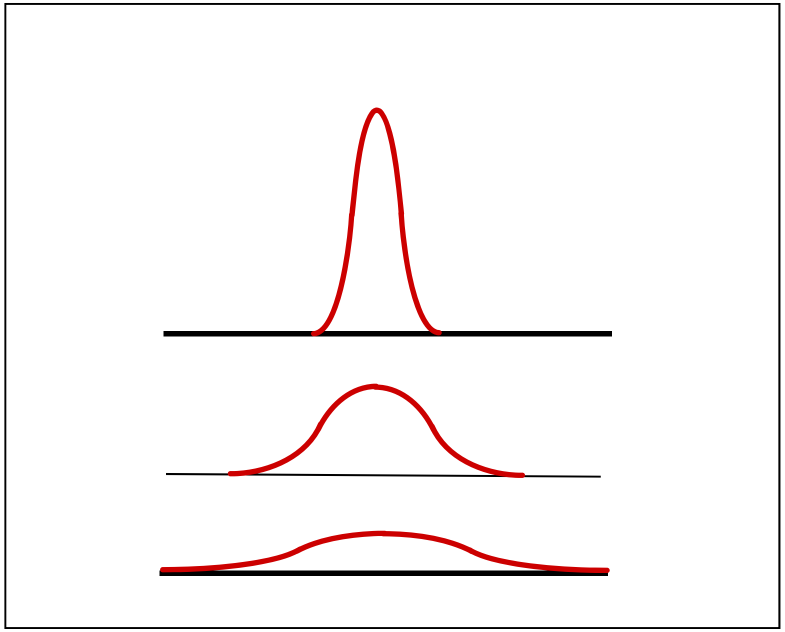
- Ensure proper drainage
- Improve quality/shear strength of the base course material
  - Coarsen the base course - add course grained aggregate and mixmil
  - Stabilize (using bituminous or hydraulic agents)
  - Use (hydrofobic) material treatment
- Reduce stresses in the existing base course
  - Add better quality material on top of in (AC or unbound aggregate)
  - Use lower tyre inflation pressure (CTIS/TPCS)

Basic solutions to Mode 2 rutting problem

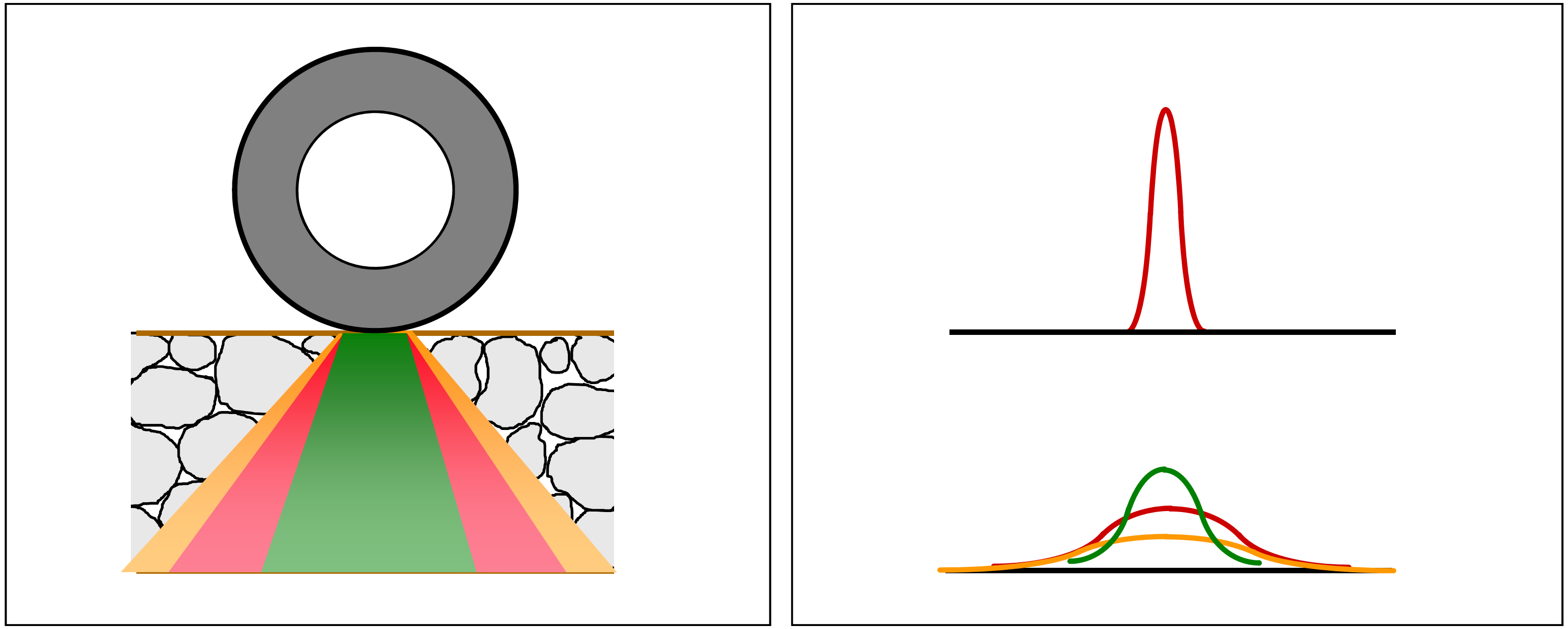
- Ensure proper drainage
- Reduce stresses in the subgrade by increasing thickness of base/sub-base course layers
- Improve quality/stiffness of the base course material
  - Stabilize (using bituminous or hydraulic agents)
  - Coarsen the base course - add course grained aggregate and mixmil
  - Use (hydrofobic) material treatment

Load spreading achieved by thickness





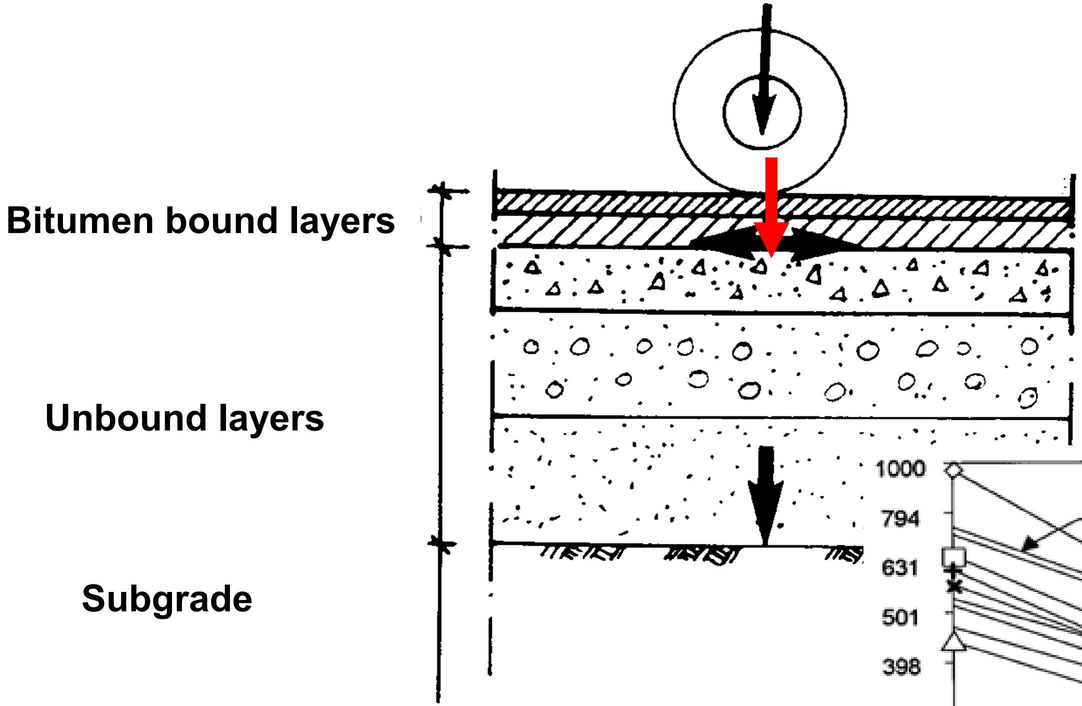
Load spreading achieved by higher stiffness aggregate

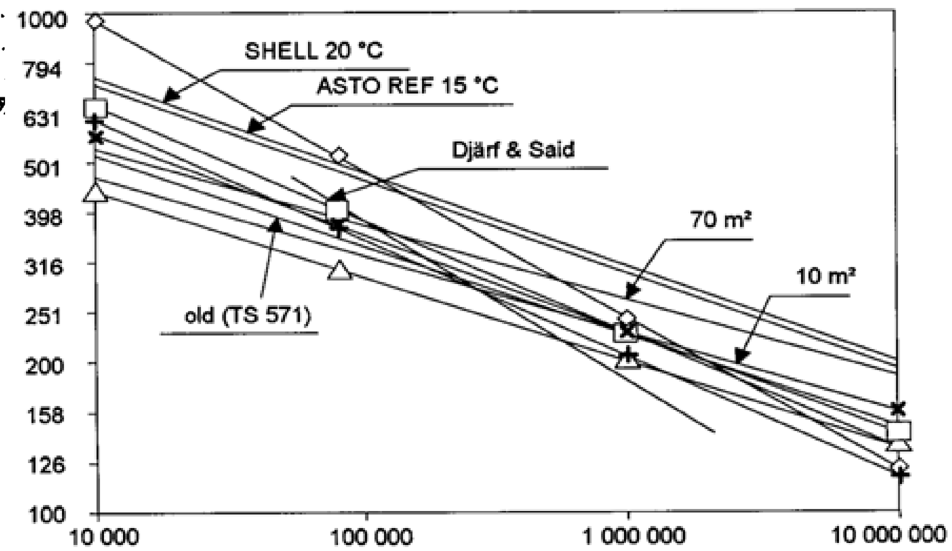


Mechanistic design of roads with high traffic volumes and strong structures

- At one load repetition stresses remain far from failure → main distress mechanisms are fatigue of bound layers and/or slow/gradual rutting of unbound layers (or subgrade)
- Design is based on analysis of stresses and strains in critical points of the structure
- Required input parameters are stiffnesses of the layer materials and the subgrade
- Fatigue/deformation models are used to estimate the service life

Mechanistic design of roads with high traffic volumes and strong structures



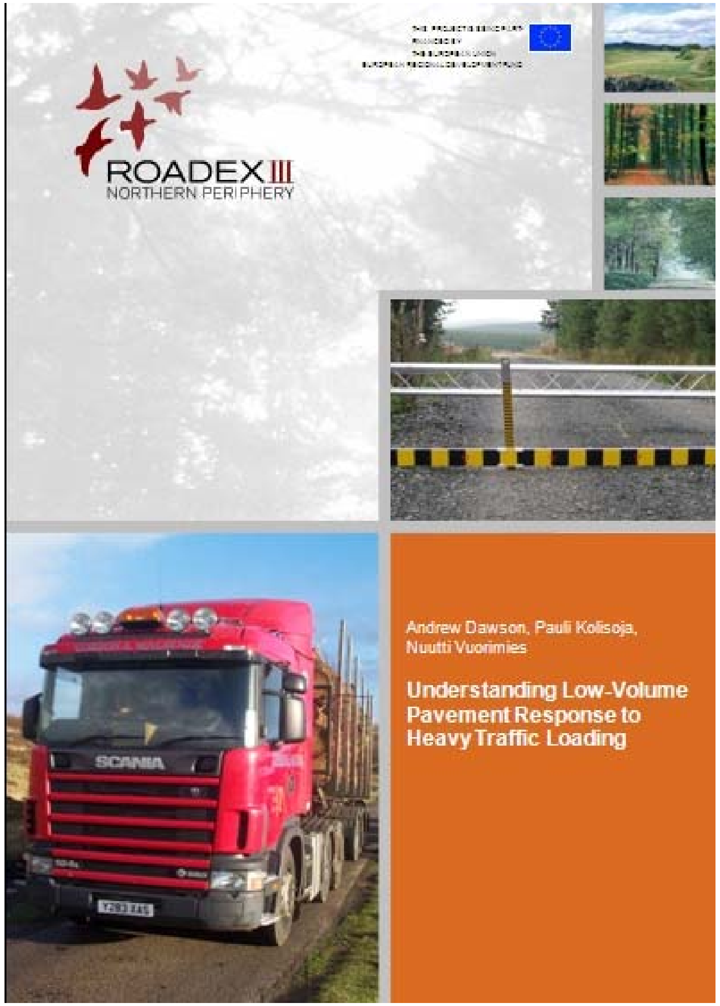


Mechanistic design of roads with low traffic volumes and weak structures

- At one load application stresses may approach close to failure → severe distresses may develop even under very few load repetitions
- A 'geotechnial approach' is required to compare the load induced stresses and the ultimate load carrying capacity of the structure and/or subgrade
- In addition to stiffnesses the required input parameters include strength parameters of the structural layers and the subgrade

ROADEX approach for Mode 1 rutting

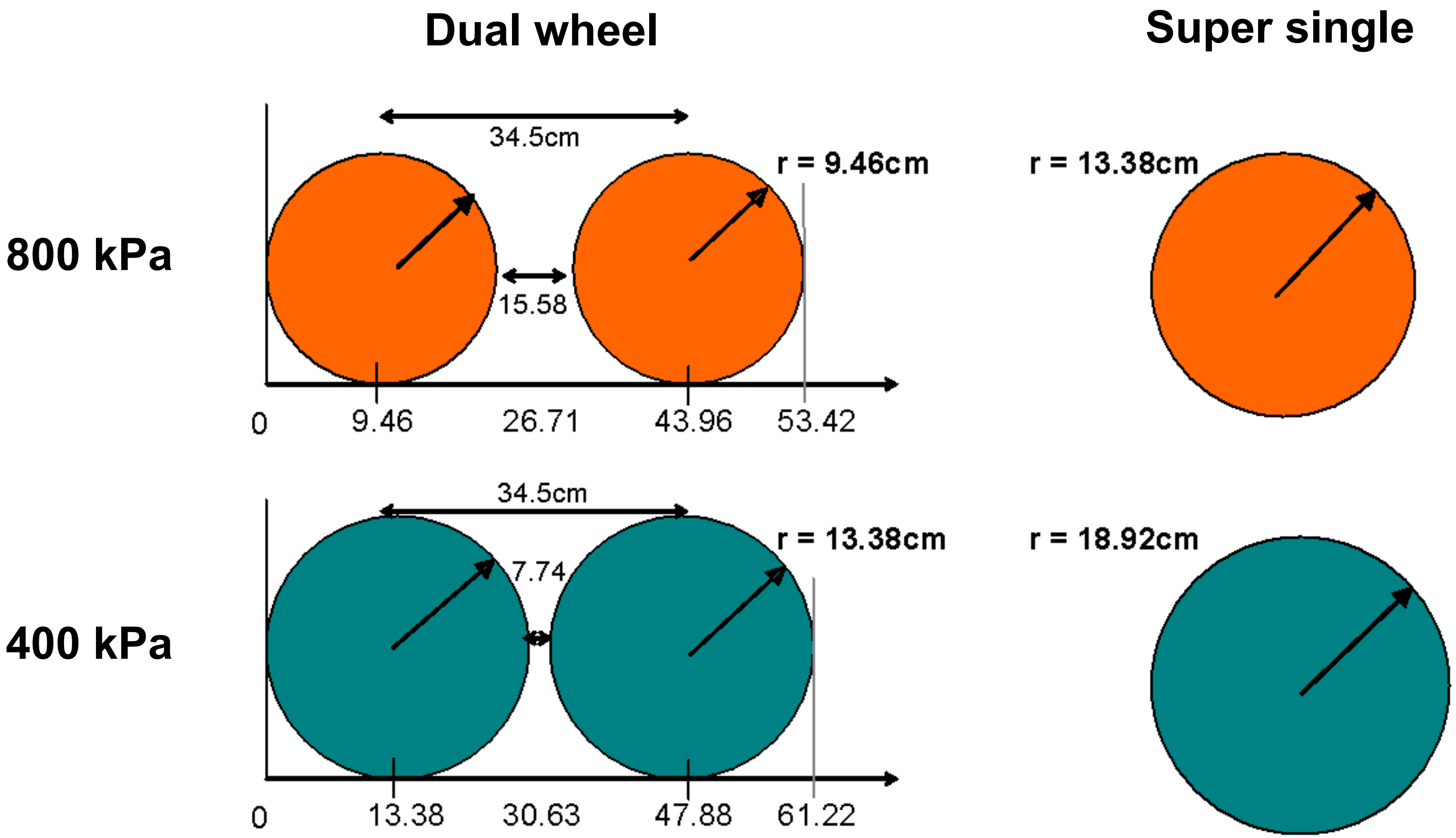
- Aimed for roads with low traffic volumes / relatively thin stuctures
- Analysis is based on ‘geotechnical approach’ i.e. the wheel load induced stresses are compared to shear strength of the aggregate



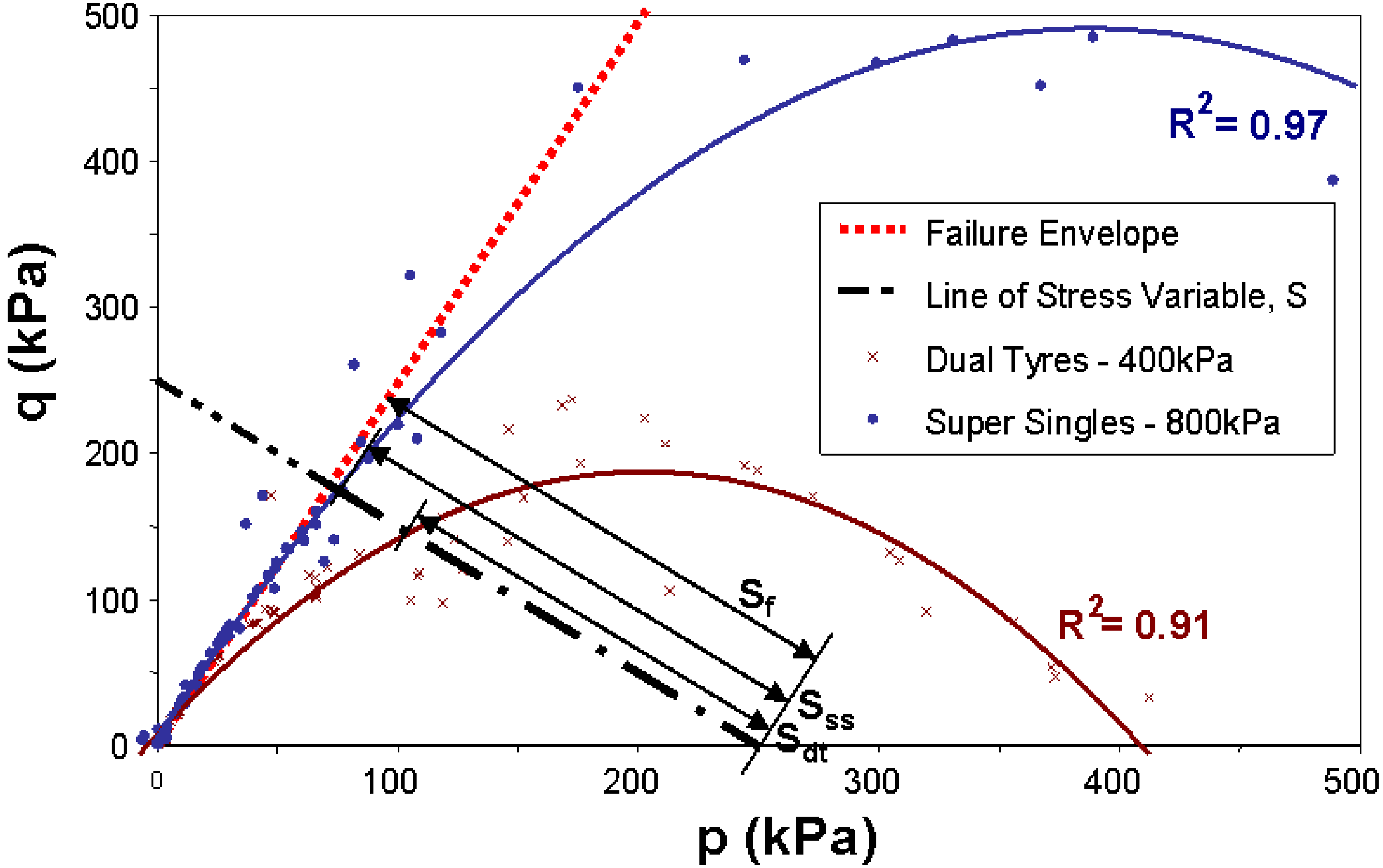
Variables included in Mode 1 design approach

- Wheel configuration: dual wheel/super single
- Tyre inflation pressure: 800 kPa/400 kPa
- Thickness of the unbound layer (in relation to the radius of loaded area under one tyre)
- Aggregate stiffness/subgrade stiffness ratio
- Mohr-Coulomb strength parameters (c and φ) for the unbound (base course) aggregate

Description of the different wheel loadings



'Proximity to failure' approach



Basic idea of Mode 1 rutting approach

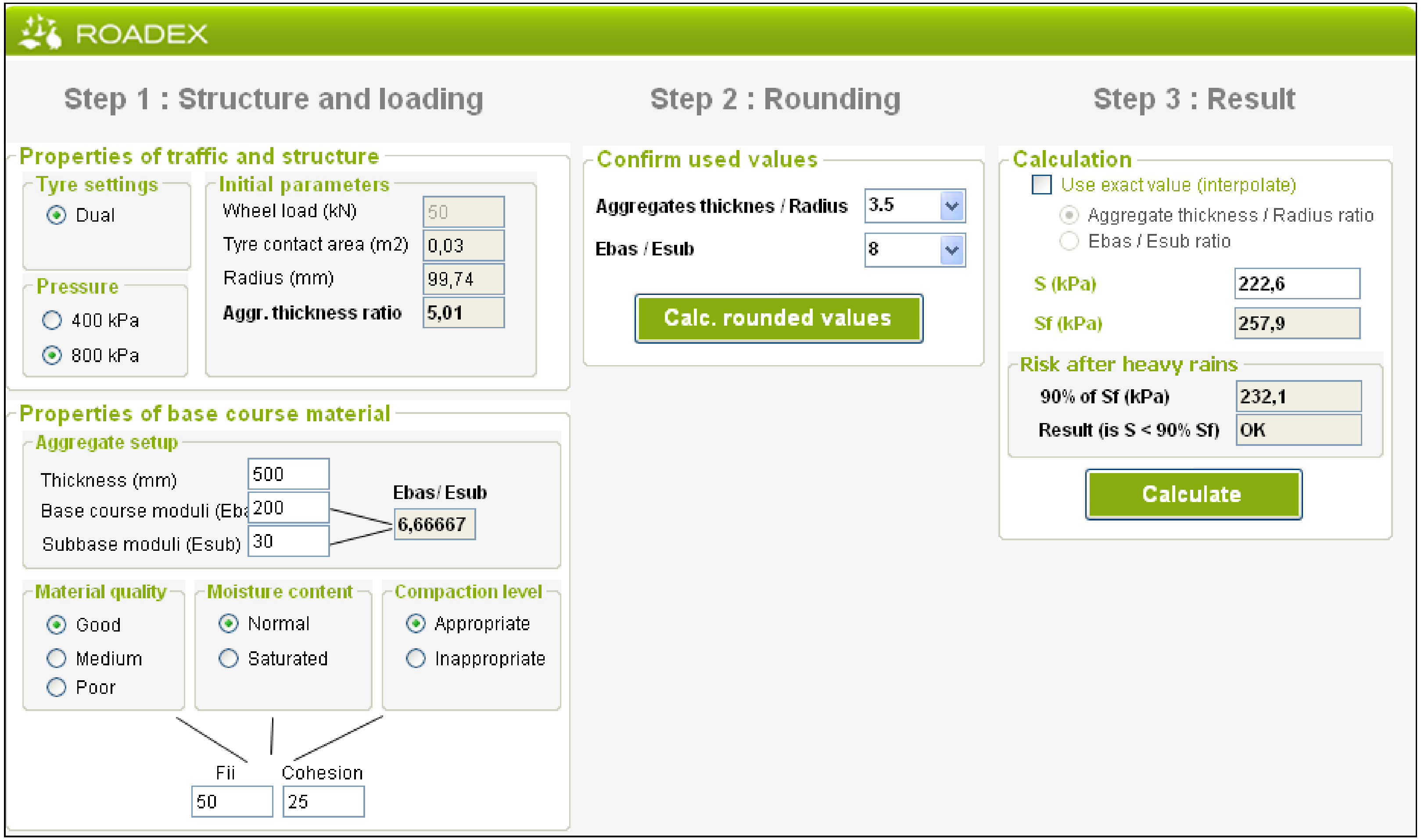
- An anaysis of stress quantities p and q (mean stress and deviator stress) corresponding to the actual loading case is made; in practise by using a set of graphs or tabulated values or a simple software tool
- ’Proximity to failure’ along the line between the points (p=250kPa, q=0) and (p=0, q=250kPa) is determined in terms of S/Sf ratio
- S/Sf ratio should not exceed 0,90 in dry conditions and 0,75 in wet conditions

Determination of S using tabulated values

Table 4 Summary of Values of Stress Variable, S, for all NIG analyses

Agg. Thick. / Load Radius Ratio	Aggregate Thickness (cm)	Stiffness Ratio (Ebas/Esub)	Tyre Pressure (kPa)	Tyre Arrangement	S (kPa)
1.0	13.5	2	400	Dual Tyres	**207.1**
1.3	17.0	2	400	Dual Tyres	**205.7**
1.7	23.0	2	400	Dual Tyres	**214.9**
2.5	33.8	2	400	Dual Tyres	**214.5**
3.5	47.3	2	400	Dual Tyres	**215.1**
1.0	13.5	4	400	Dual Tyres	**221.3**
1.3	17.0	4	400	Dual Tyres	**212.3**
1.7	23.0	4	400	Dual Tyres	**217.9**
2.5	33.8	4	400	Dual Tyres	**209.2**
3.5	47.3	4	400	Dual Tyres	**208.7**
1.0	13.5	8	400	Dual Tyres	**224.5**
1.3	17.0	8	400	Dual Tyres	**217.7**
1.7	23.0	8	400	Dual Tyres	**214.0**
2.5	33.8	8	400	Dual Tyres	**209.8**

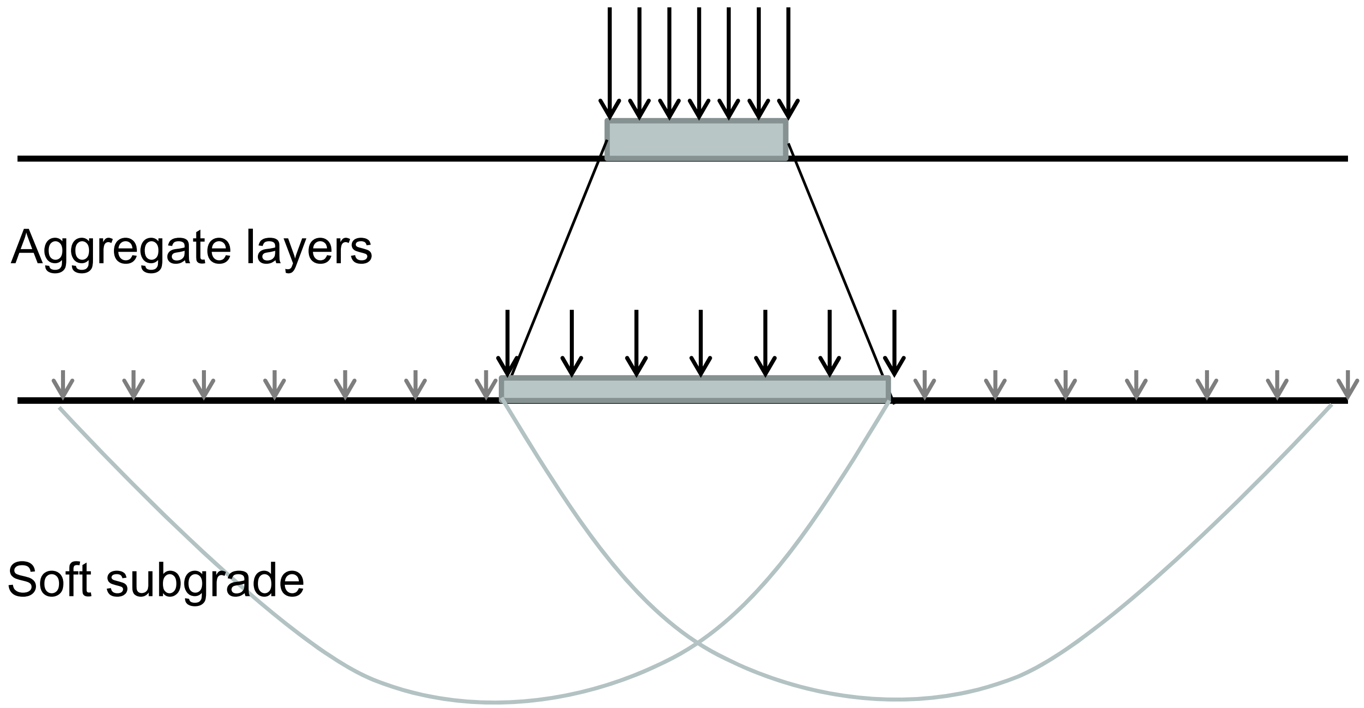
Mode 1 design using a software tool to be available at: www.roadex.org



Development of ROADEX approach for Mode 2 rutting – basic idea

- A 'geotechnical approach' is aimed to be developed also for Mode 2 rutting
- Analysis of stress-strain distribution along the aggregate layers → distribution of vertical stress on the subgrade surface level
- Estimation of the ultimate load carrying capacity of the subgrade is made by means of a geotechnical bearing capacity formula
- Sufficient factor of safety against failure of the subgrade is required

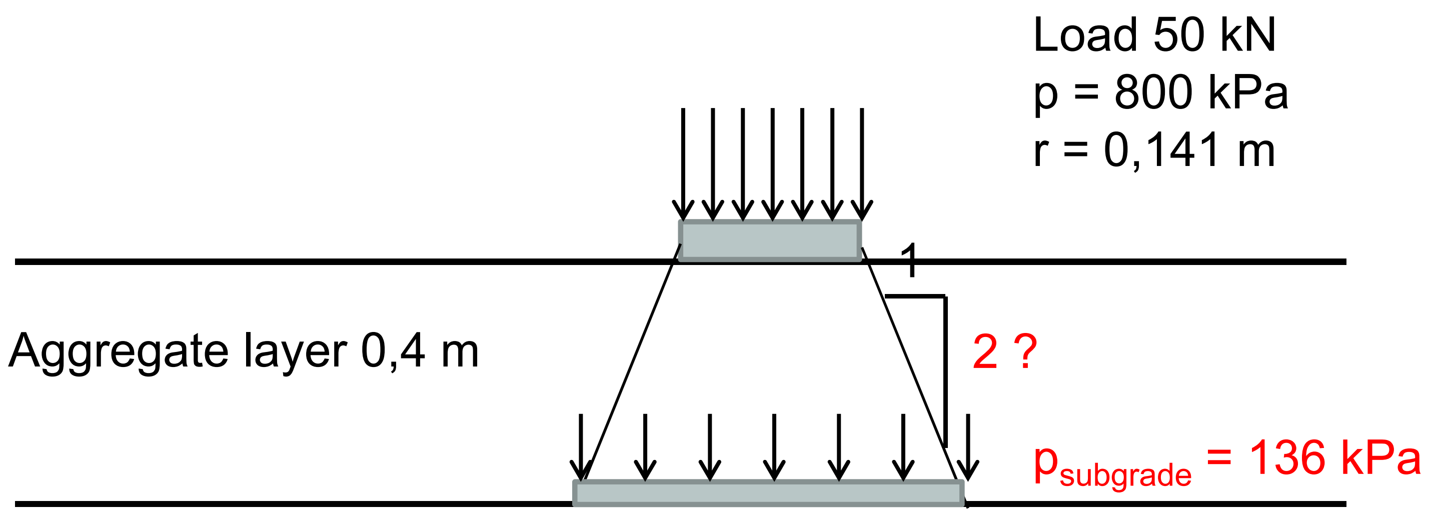
Development of ROADEX approach for Mode 2 rutting – basic idea



Key questions are now:

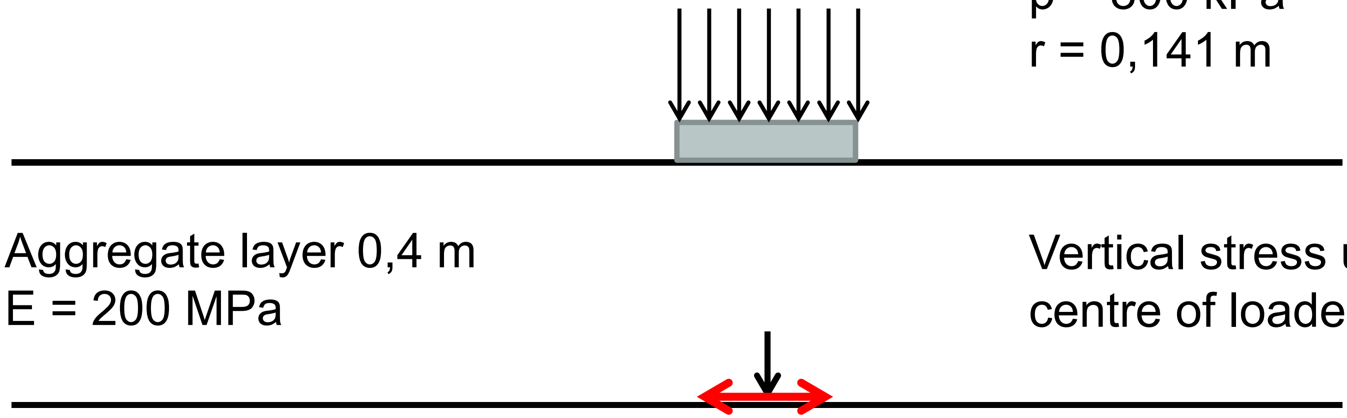
1. Stress distribution on the subgrade surface level
2. Strength of the subgrade soil (and the aggregate layers)

Calculation of stress distribution using the "1:2 approach"



Calculation of stress distribution using a multi-layer linear elastic software I

Load 50 kN
p = 800 kPa
r = 0,141 m



Aggregate layer 0,4 m
E = 200 MPa

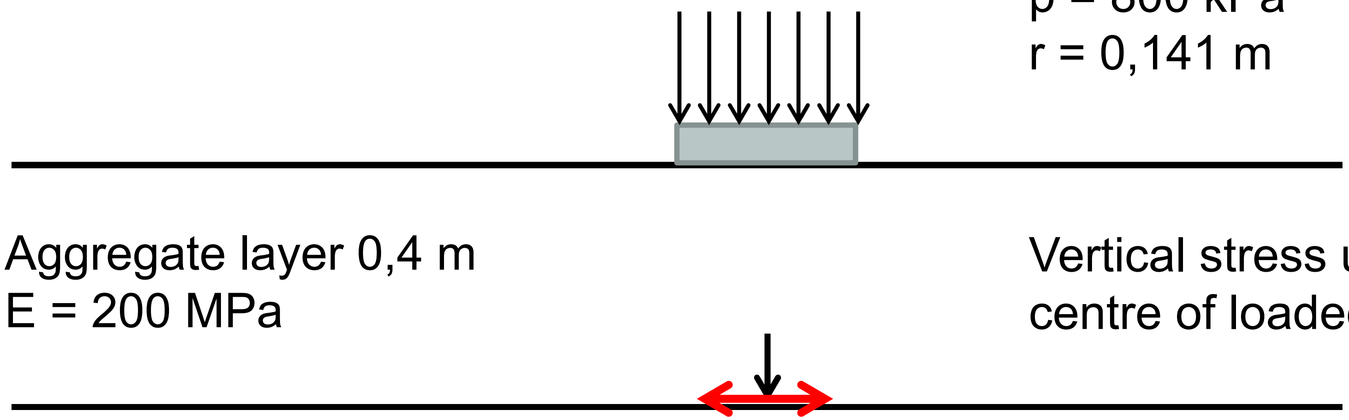
Vertical stress under the centre of loaded area 69 kPa

Subgrade
E = 40 MPa

Tensile stress at the base of aggregate layer 165 kPa !

Calculation of stress distribution using a multi-layer linear elastic software II

Load 50 kN
p = 800 kPa
r = 0,141 m



Aggregate layer 0,4 m
E = 200 MPa

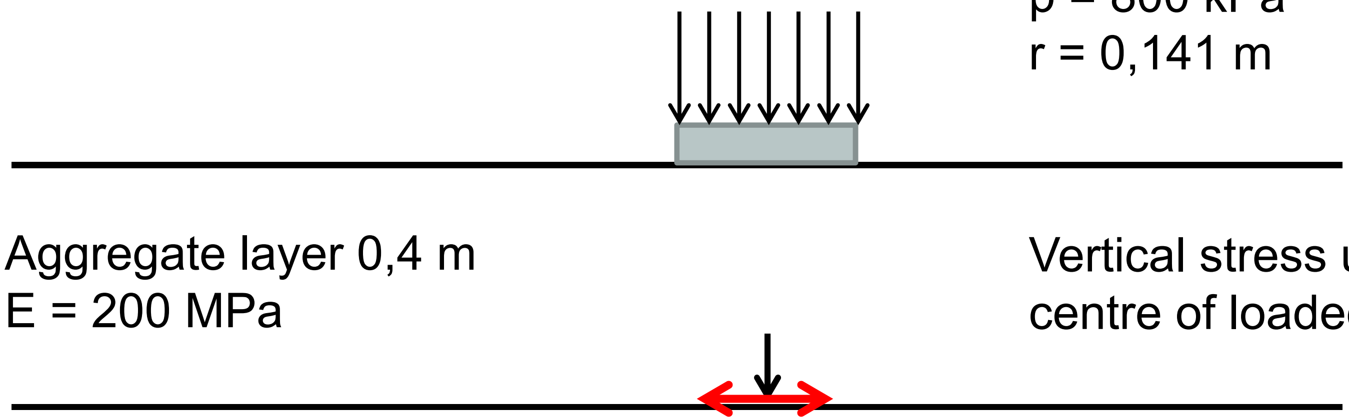
Vertical stress under the centre of loaded area 47 kPa !

Subgrade
E = 20 MPa

Tensile stress at the base of aggregate layer 242 kPa !

Calculation of stress distribution using a multi-layer linear elastic software III

Load 50 kN
p = 800 kPa
r = 0,141 m



Aggregate layer 0,4 m
E = 200 MPa

Vertical stress under the centre of loaded area 31 kPa !

Subgrade
E = 10 MPa

Tensile stress at the base of aggregate layer 314 kPa !

Development of ROADEX approach for Mode 2 rutting – a practical problem

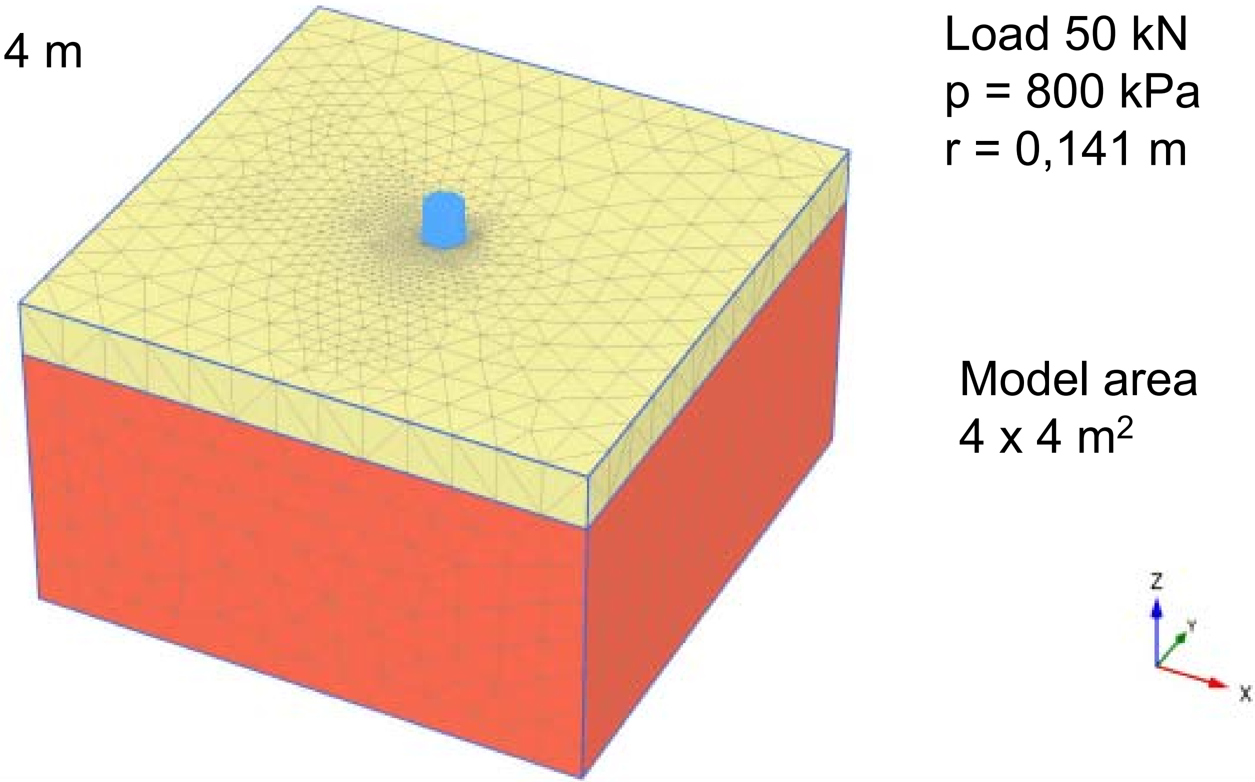
- On soft subgrades a typical situation is that aggregate stiffness is > 10 times the subgrade stiffness
- If a multi-layer linear elastic software (or linear elastic FE model) is used in the stress-strain analysis, fictitious tensile stresses are calculated on the base of the aggregate layer

  → estimation of the vertical stresses acting on the subgrade surface are calculated severely wrong

PLAXIS-3D FE Moled of a single wheel

Structural layers 0,4 m
E = 200 MPa
φ = 50 °
c = 25 kPa

Subgrade 2,0 m
E = 40 MPa



Load 50 kN
p = 800 kPa
r = 0,141 m

Model area
4 x 4 m^2

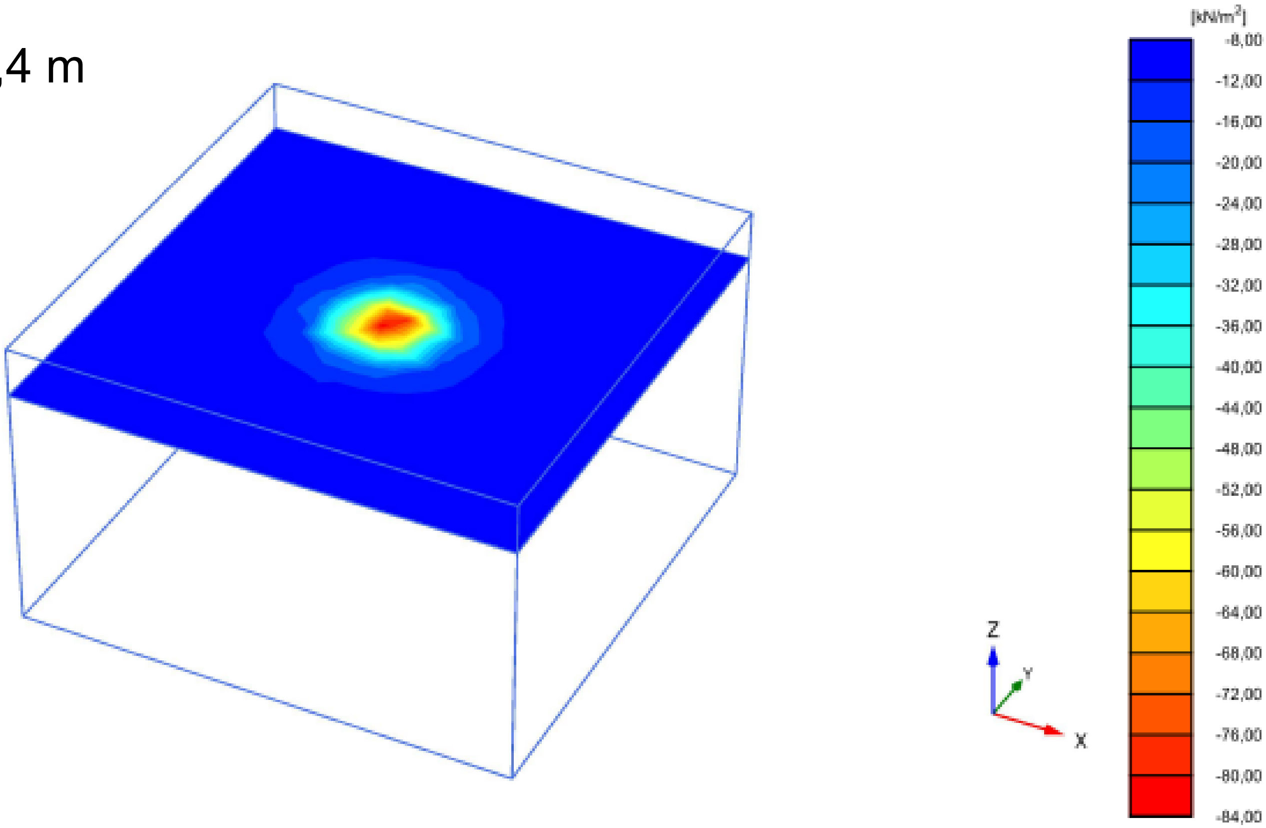
Deformed mesh |u| (scaled up 100 times)

Maximum value = $1{,}574 \cdot 10^{-3}$ m (at Node 3988)

Vertical stress distribution on subgrade surface

Structural layers 0,4 m
E = 200 MPa
φ = 50 °
c = 20 kPa

Subgrade 2,0 m
E = 40 MPa



Cartesian effective stress σ'_{zz}

Maximum value = -8,362 kN/m^2

Minimum value = -81,87 kN/m^2

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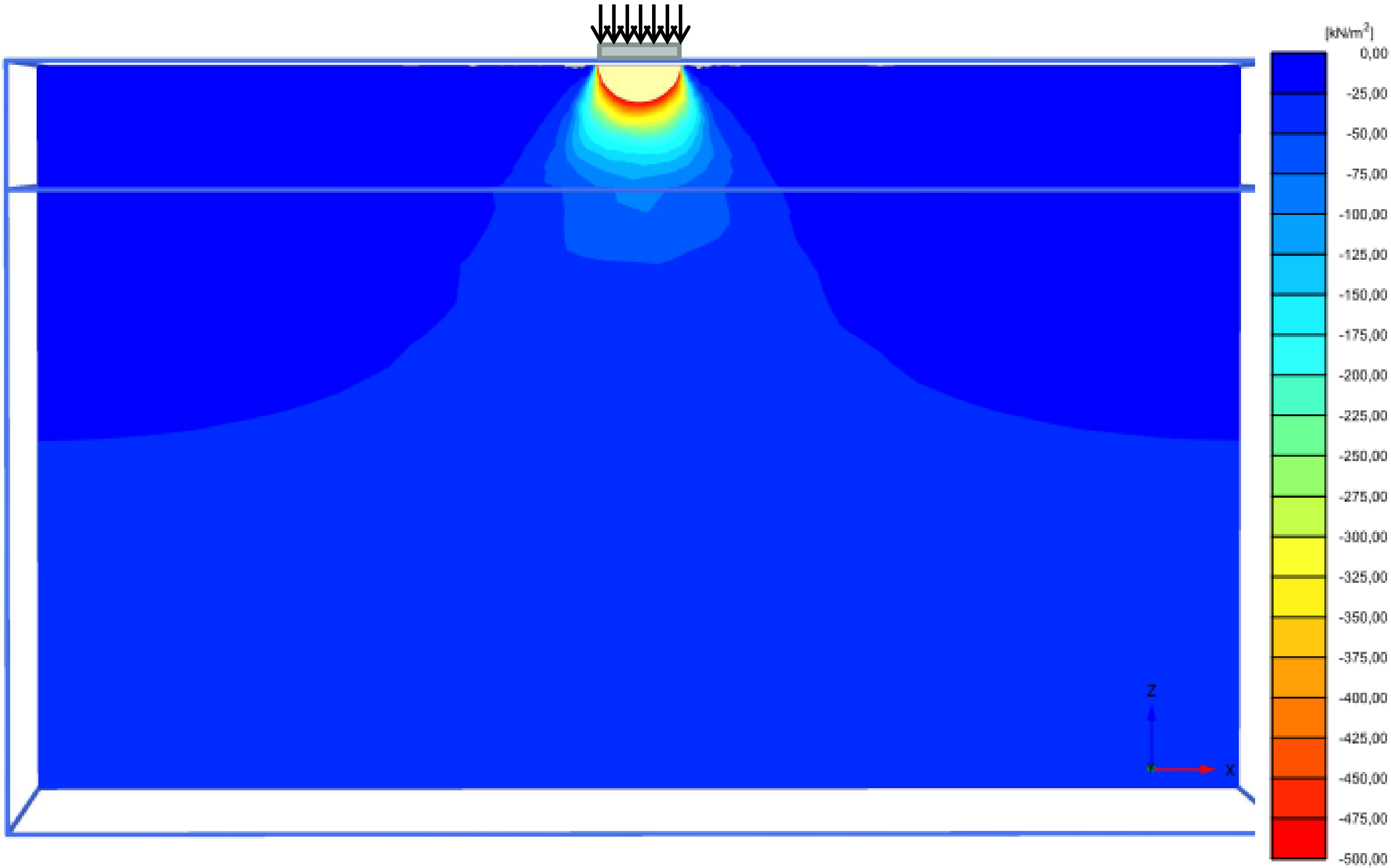
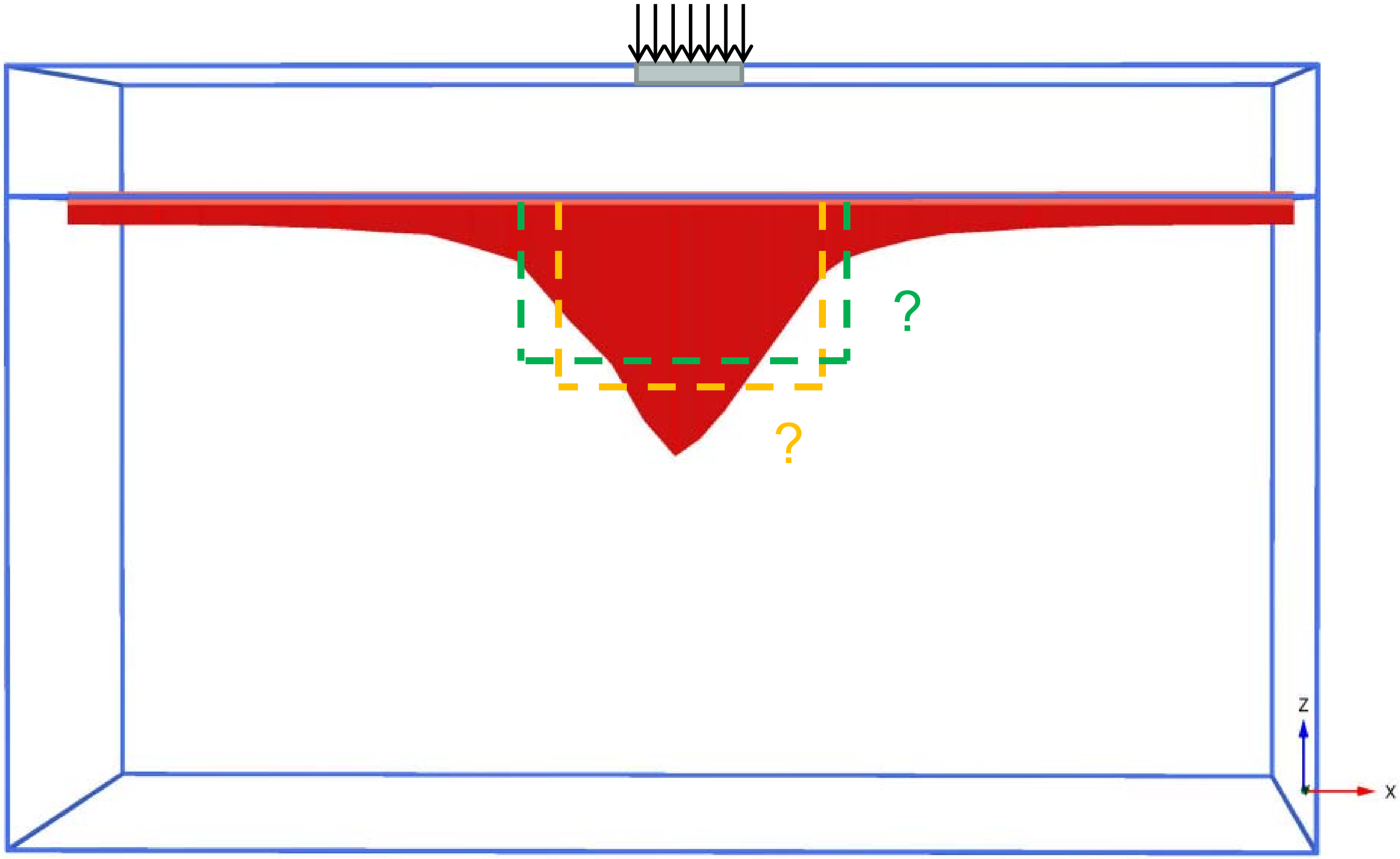
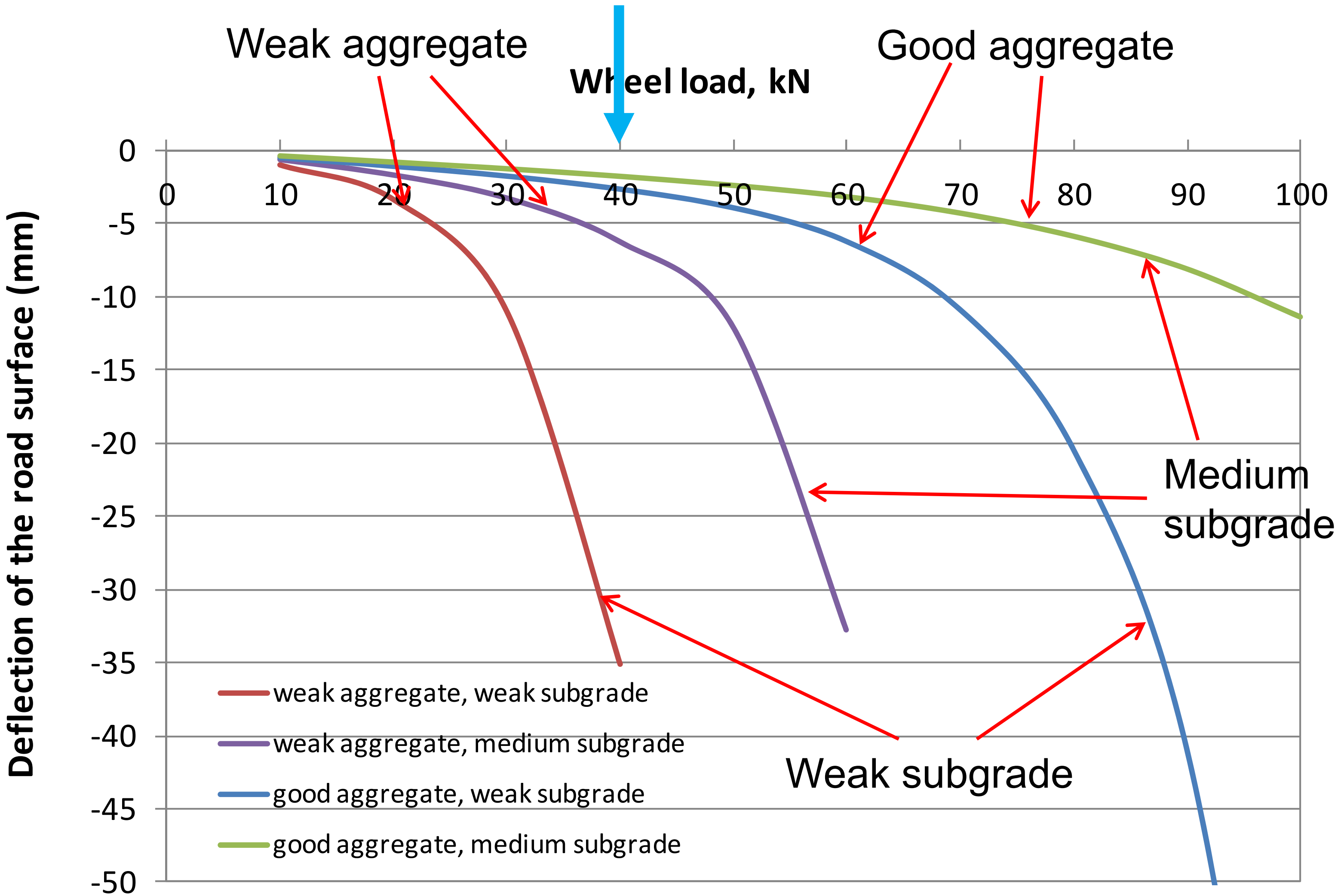
Vertical stress distribution in a cross section



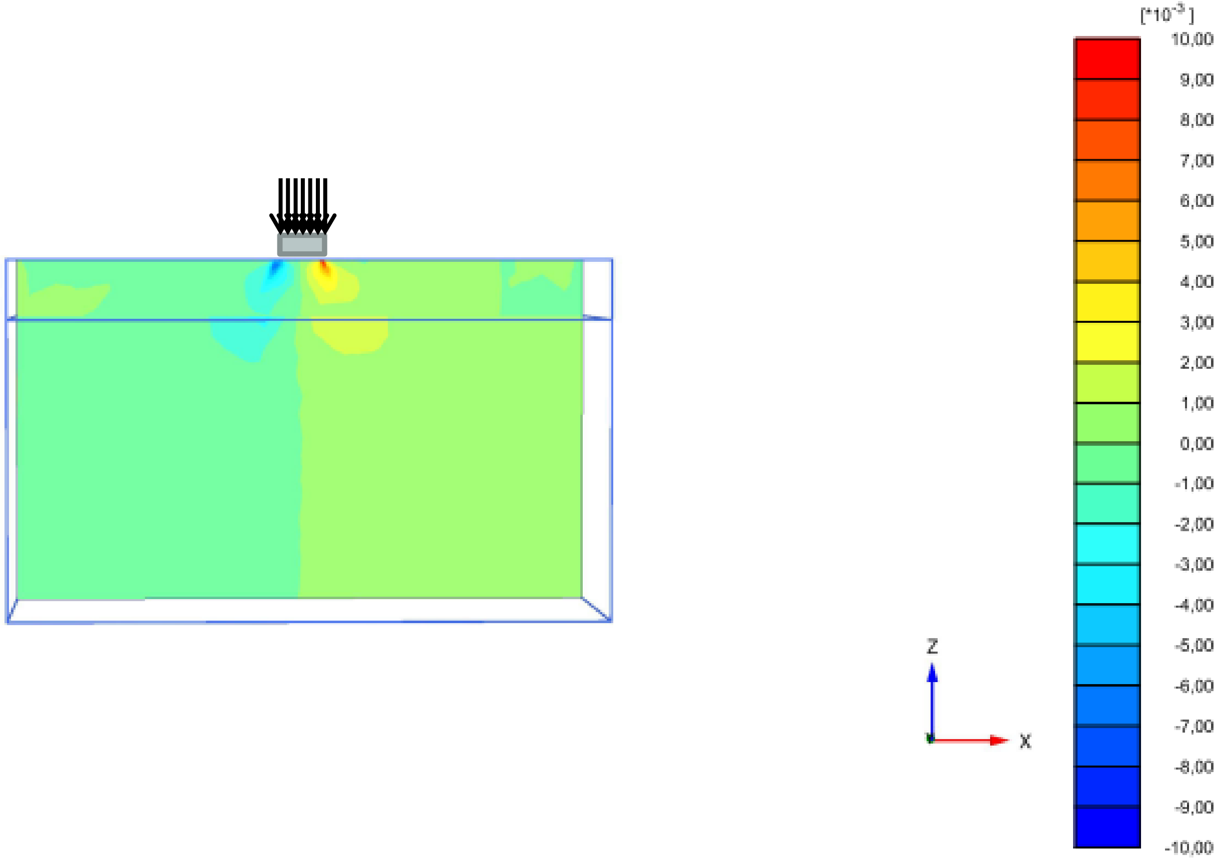
Vertical stress distribution on the subgrade surface in a cross section



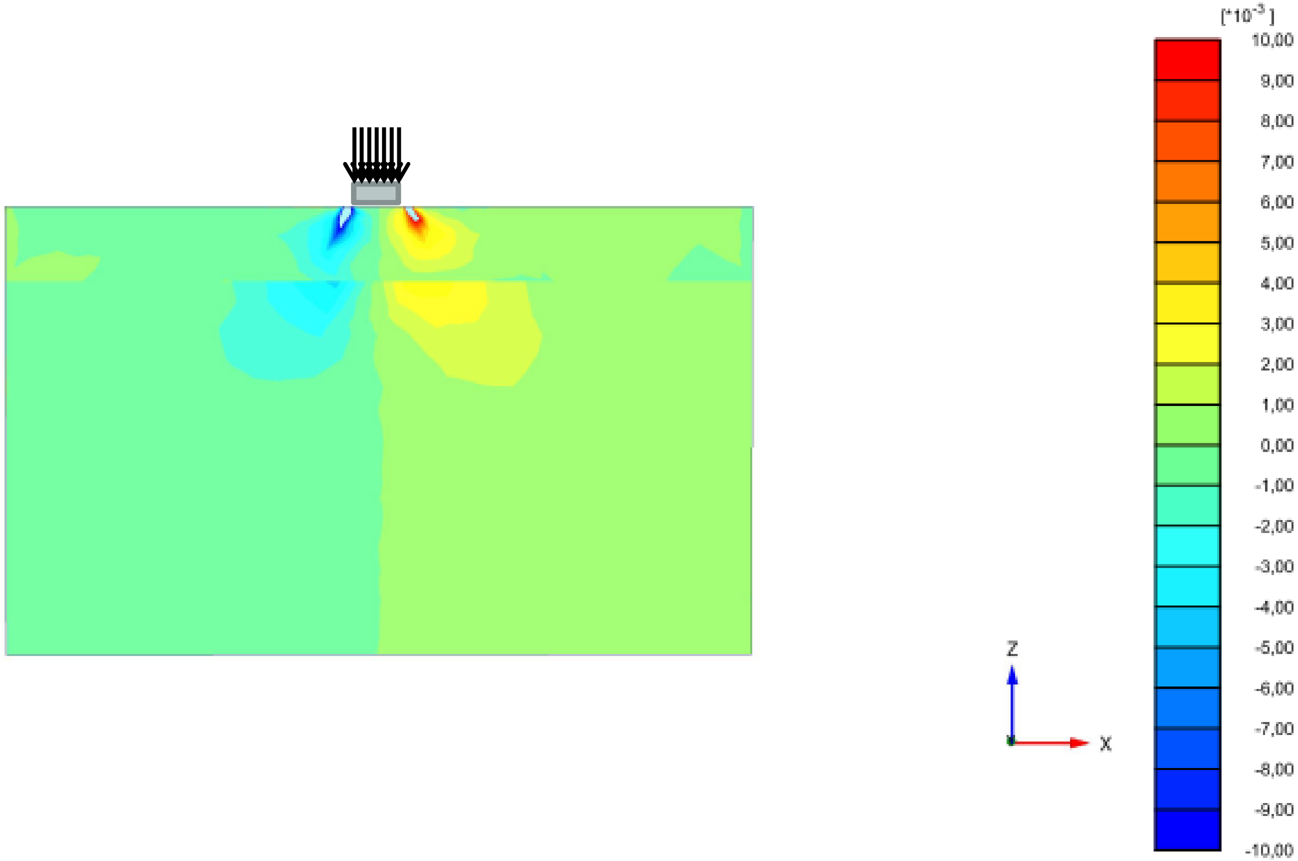
FE-simulation of single wheel loading



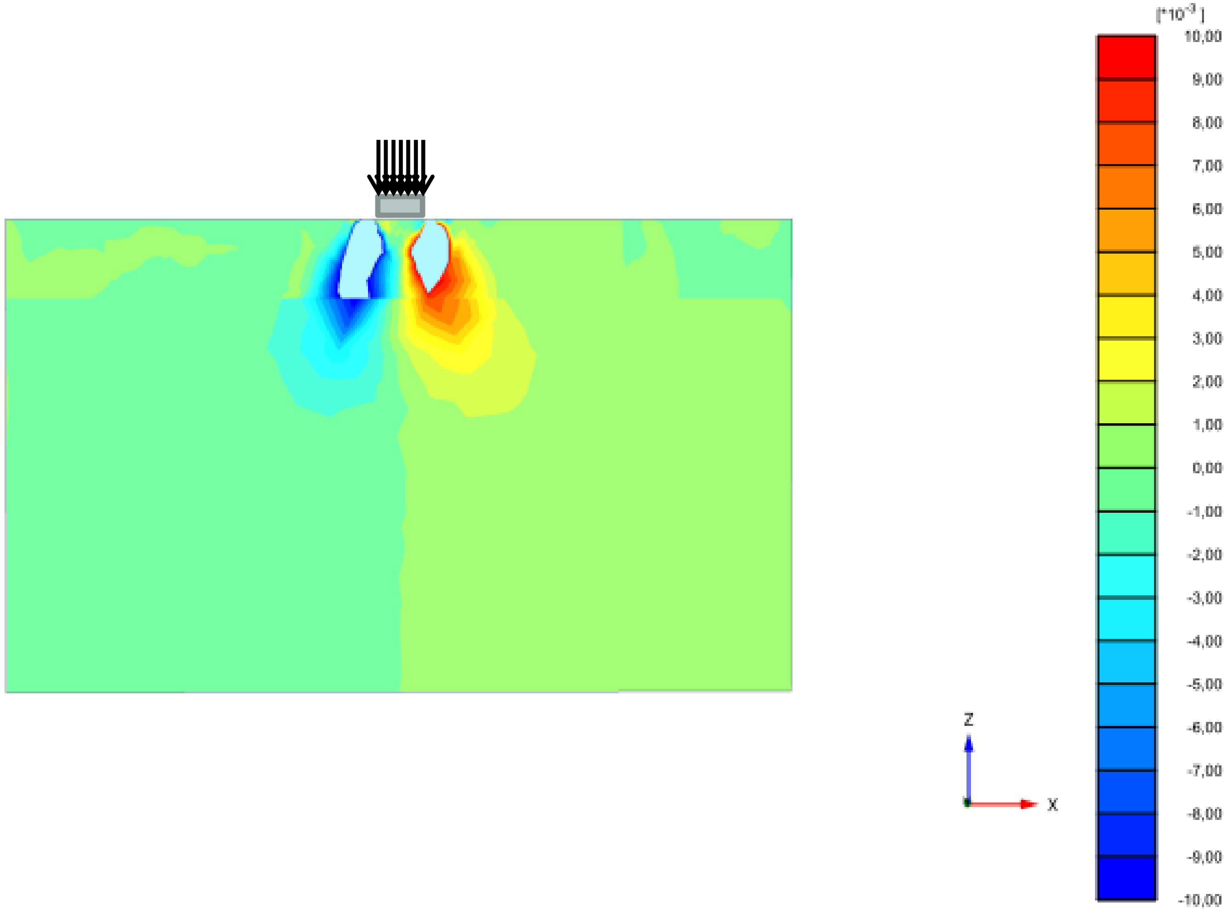
Shear strain distribution: P = 40 kN, good aggregate, medium subgrade



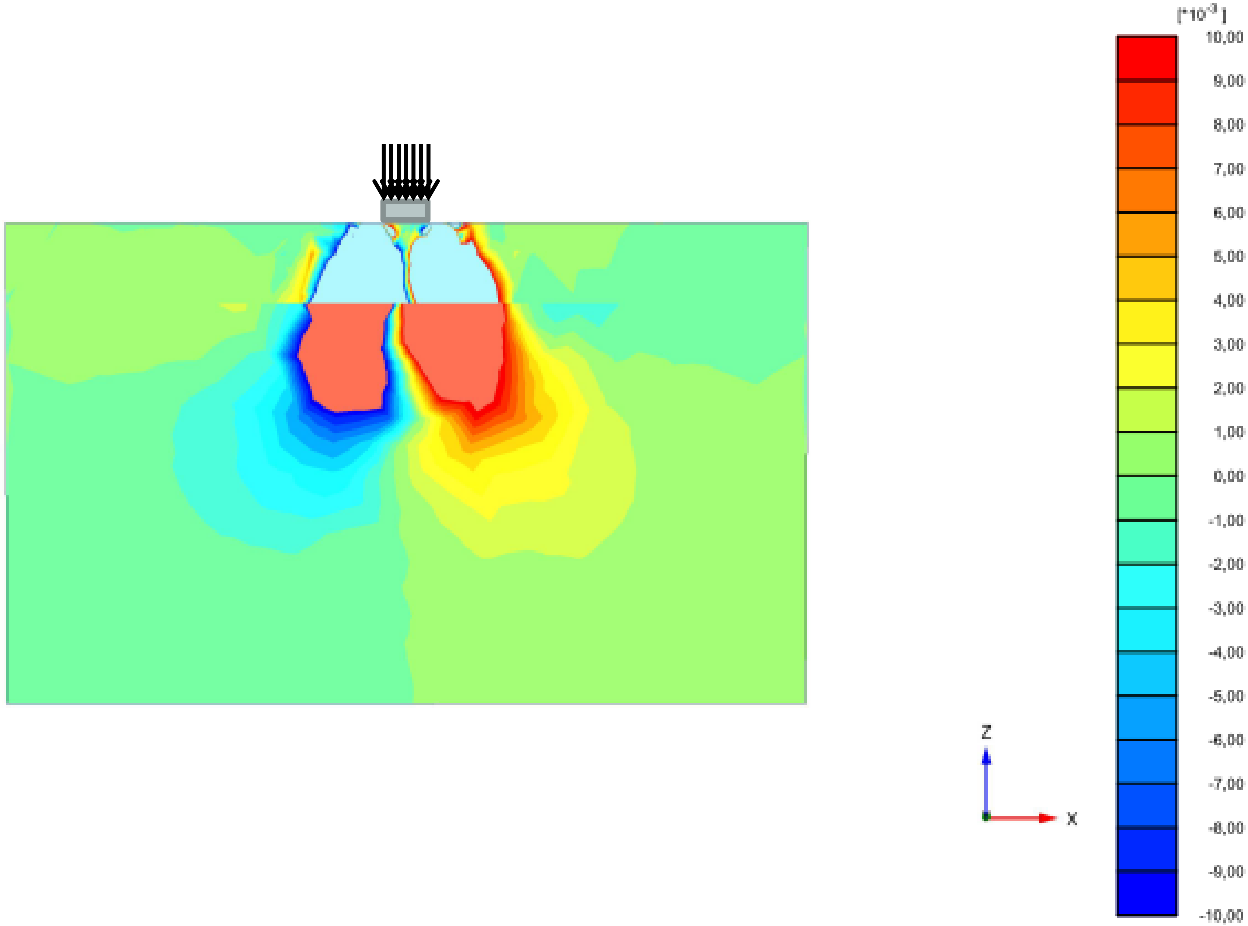
Shear strain distribution: P = 40 kN, good aggregate, weak subgrade



Shear strain distribution: P = 40 kN, weak aggregate, medium subgrade



Shear strain distribution: P = 40 kN, weak aggregate, weak subgrade



Variables that should be included into the FEM analysis

- Thickness of the aggregate layers
- Aggregate material properties: shear strength parameters (and stiffness)
- Subgrade shear strength (and stiffness)
- Wheel configuration; dual or single
- (Tyre inflation pressure)

Determination of a basic set of shear strength parameters for design against rutting

- Test variables
  - Material type/origin
  - Grain size distribution (especially the fines content)
  - Moisture content
  - Density

- The results are to be implemented into the software tool available at the ROADEX website

Suggested values for strength parameters

Material quality	Moisture content	Compaction level	Cohesion*	Phi (Φ)
Good	Normal	OK / Appropriate	25	50
Good	Normal	Not Ok / Inappropriate	25	37.5
Good	High	OK / Appropriate	10	50
Good	High	Not Ok / Inappropriate	10	37.5
Medium	Normal	OK / Appropriate	10	45
Medium	Normal	Not Ok / Inappropriate	10	30
Medium	High	OK / Appropriate	5	45
Medium	High	Not Ok / Inappropriate	5	30
Poor	Normal	OK / Appropriate	10	40
Poor	Normal	Not Ok / Inappropriate	10	22.5
Poor	High	OK / Appropriate	0	40
Poor	High	Not Ok / Inappropriate	0	22.5

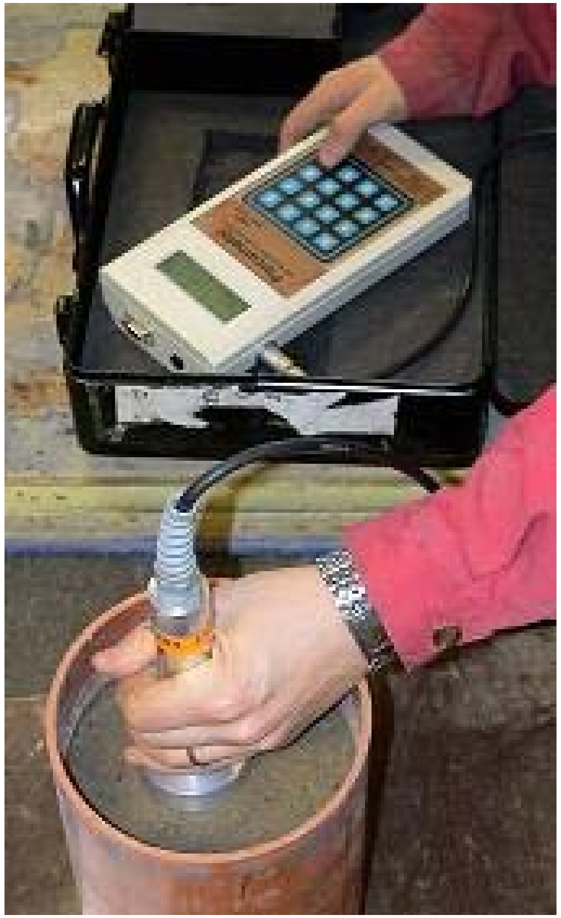
Criteria for good quality material

- Tube Suction (TS) test result Er < 9, **and**
- Fines content < 5% **,and**
- Material does not contain mica or other weathering minerals.

Additional criteria that can also be considered include:

- Specific surface area of fines < 3000 m^2/kg
- Water adsorption index < 2

Tube Suction (TS) test



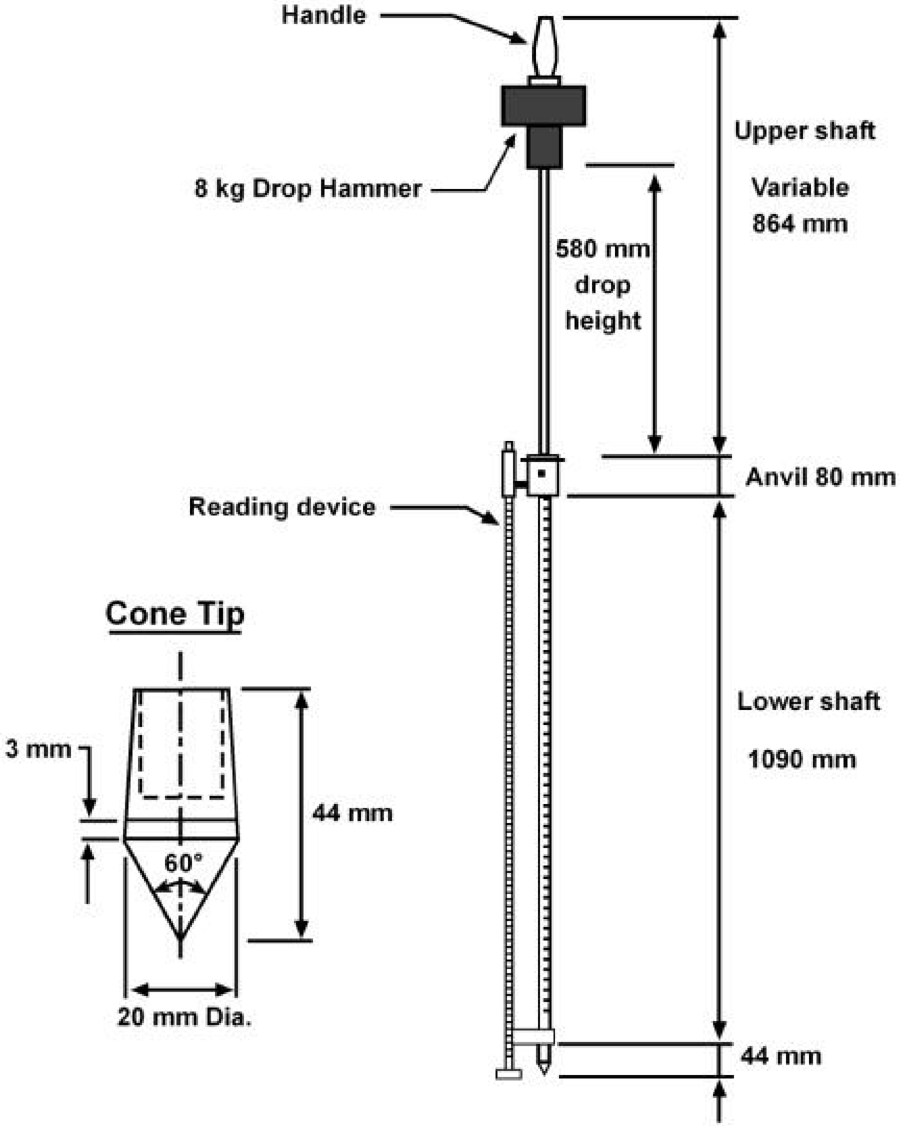
Criteria for medium quality material

- TS-test result 9 < Er < 16, **and**
- Fines content < 12 %
- If material contains high amount of mica or other poor quality weathering minerals, fines content < 7 %

Criteria for poor quality material

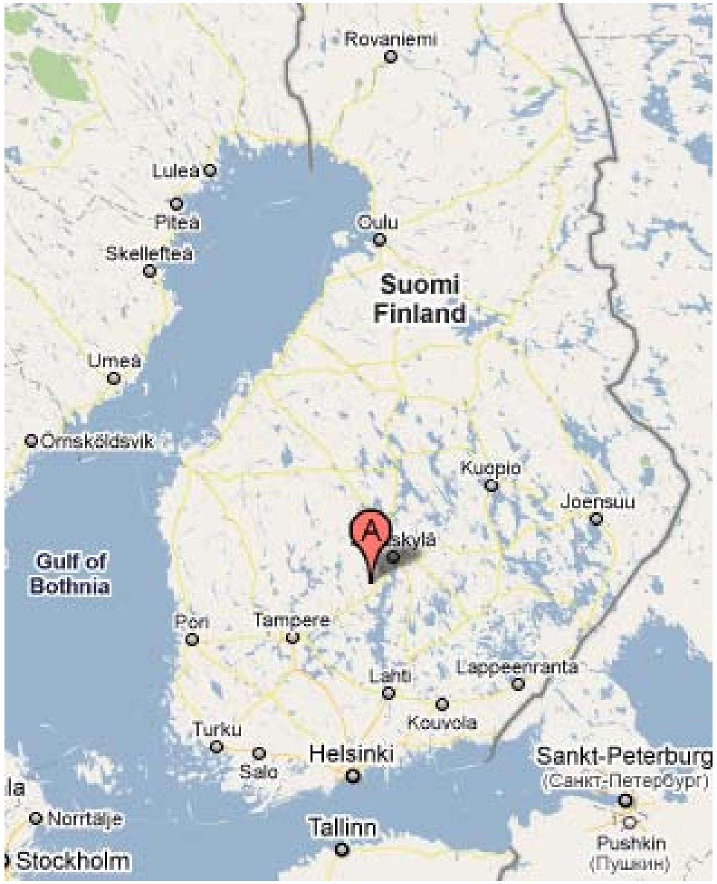
- TS-test result Er > 16, **or**
- Fines content > 12 %. If the material contains a high amount of mica or other poor quality weathering minerals, fines content > 7 %

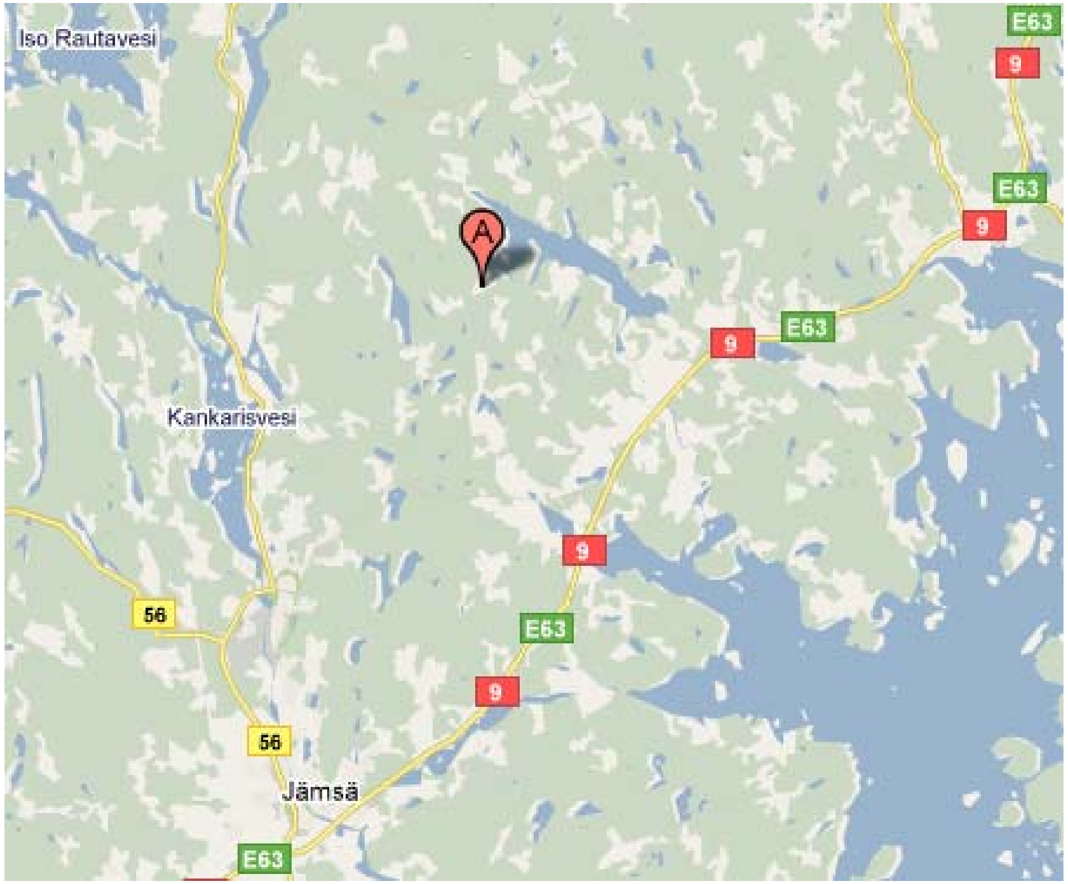
Dynamic Cone Penetration (DCP) test



Leightweight FWD / Dynamic PBT

Ehikki-Juokslahti I, reducing permanent deformations by improving drainage

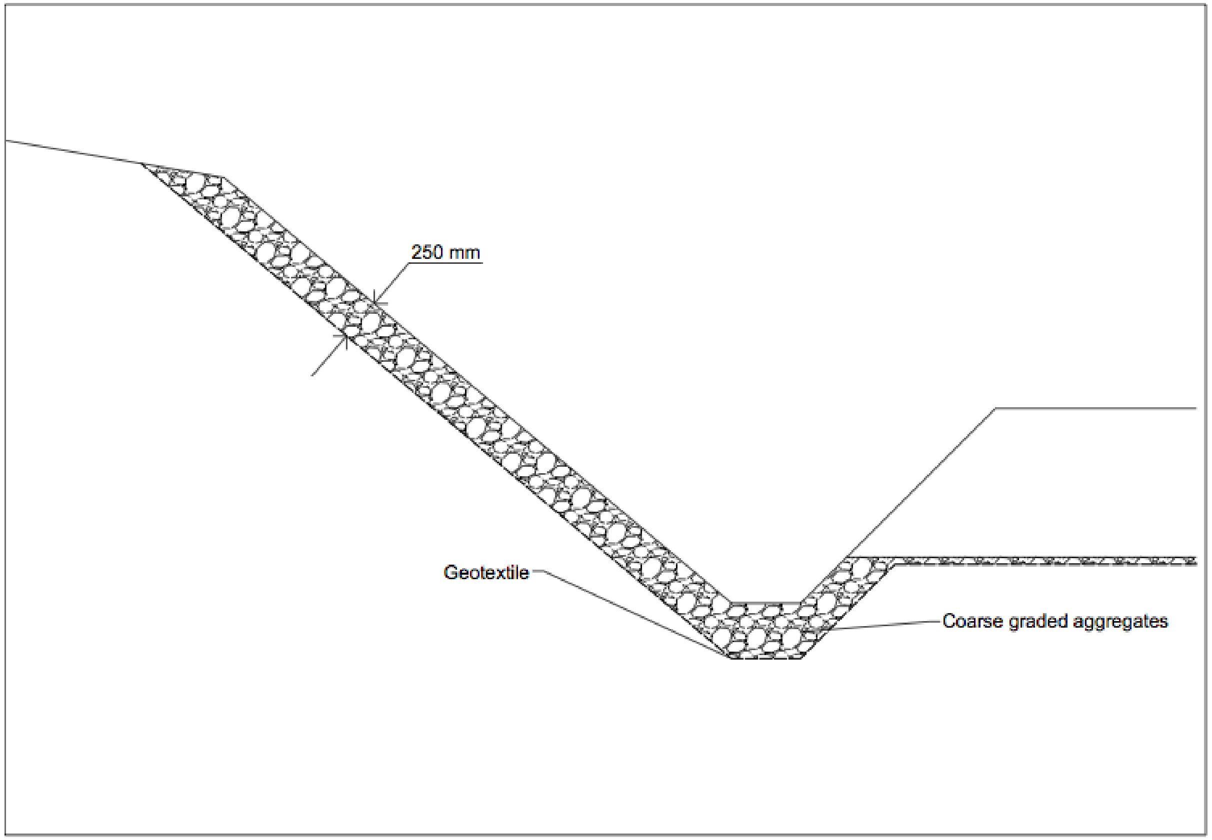




Ehikki-Juokslahti I, reducing permanent deformations by improving drainage

Spring time bearing capacity loss and permanent deformation site due to 'disappearing ditch' in a silty moraine slope.

Ehikki-Juokslahti I, reducing permanent deformations by improving drainage



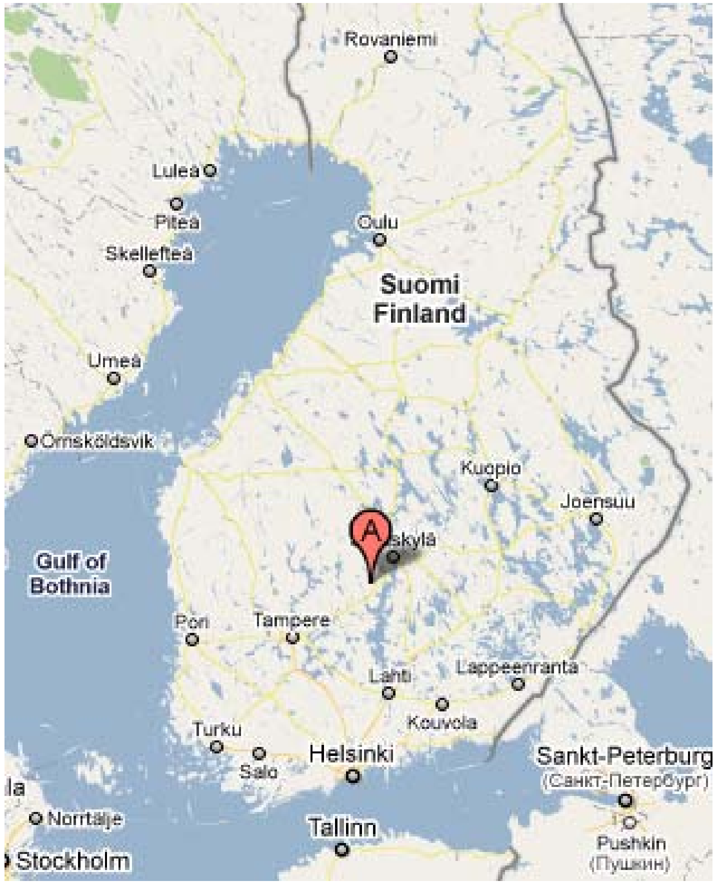
'Standard ROADEX solution' to make a long lasting drainage improvement in a condition were the available space is not a limitation.

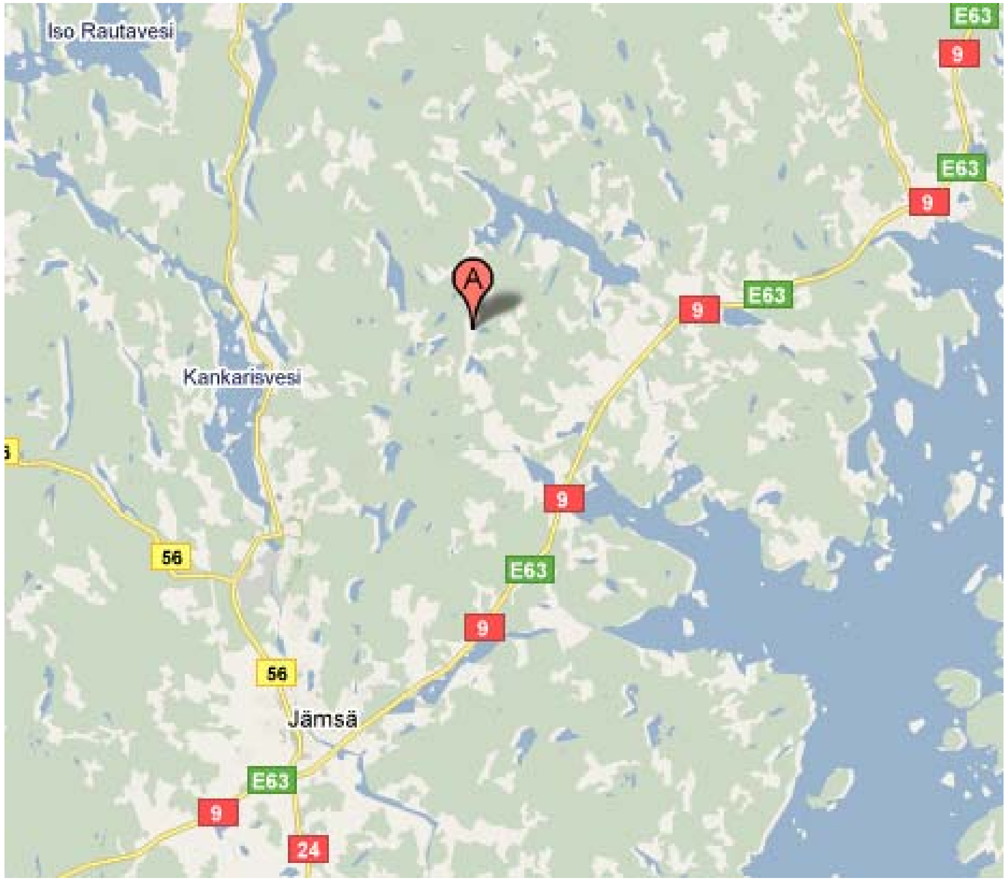
Ehikki-Juokslahti I, reducing permanent deformations by improving drainage

Ehikki-Juokslahti I, drainage improvement structure after the first winter

Ehikki-Juokslahti I, drainage improvement 'reference' structure before cleaning the ditch in 2010 and after the first spring thaw in 2011

Ehikki-Juokslahti II, reducing permanent deformations by improving drainage





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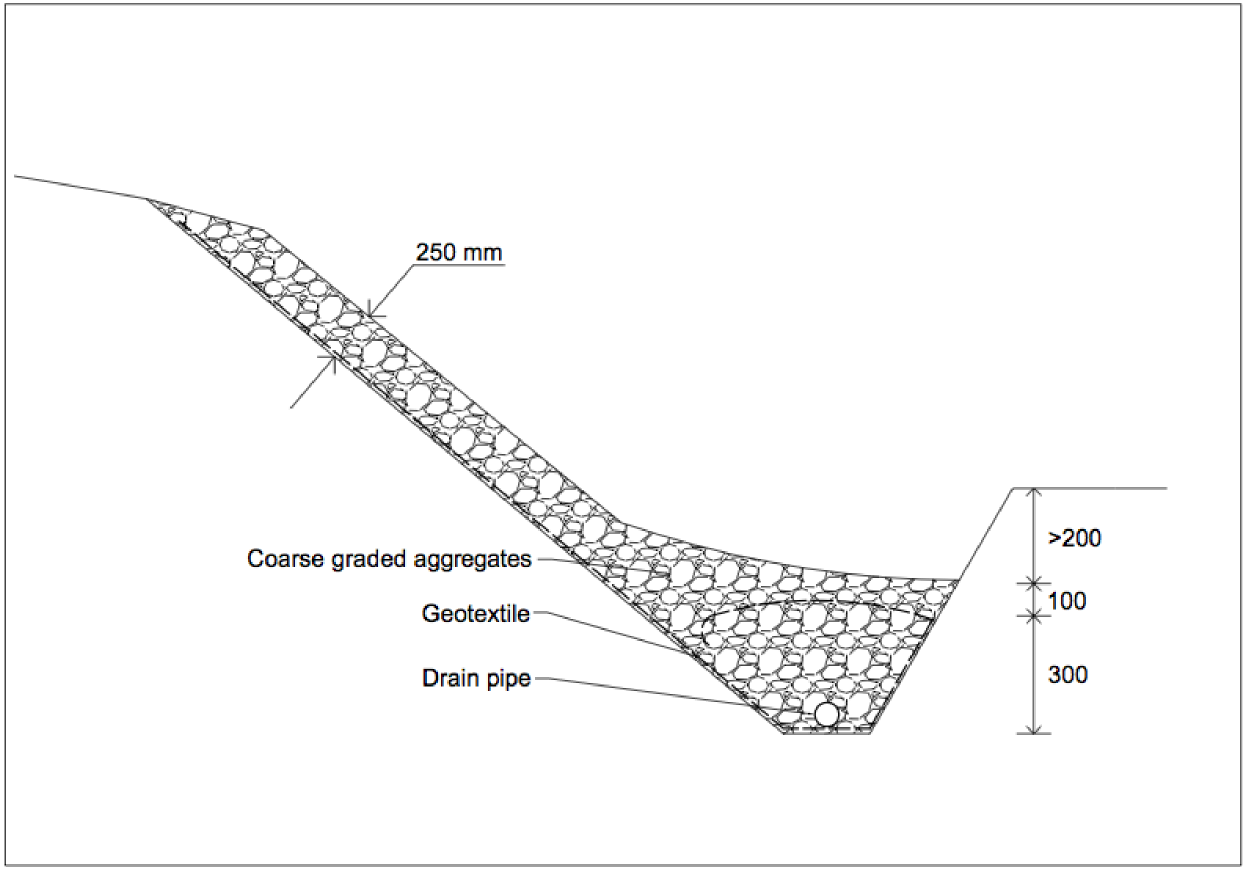
Ehikki-Juokslahti II, reducing permanent deformations by improving drainage

Severe spring time bearing capacity loss and permanent deformation site due to side sloping ground surface – available road area very limited.

Ehikki-Juokslahti II, reducing permanent deformations by improving drainage



'Adjusted ROADEX solution' to make a long lasting drainage improvement in a sloped ground surface were the available space is a strict limitation.

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Ehikki-Juokslahti II, reducing permanent deformations by improving drainage

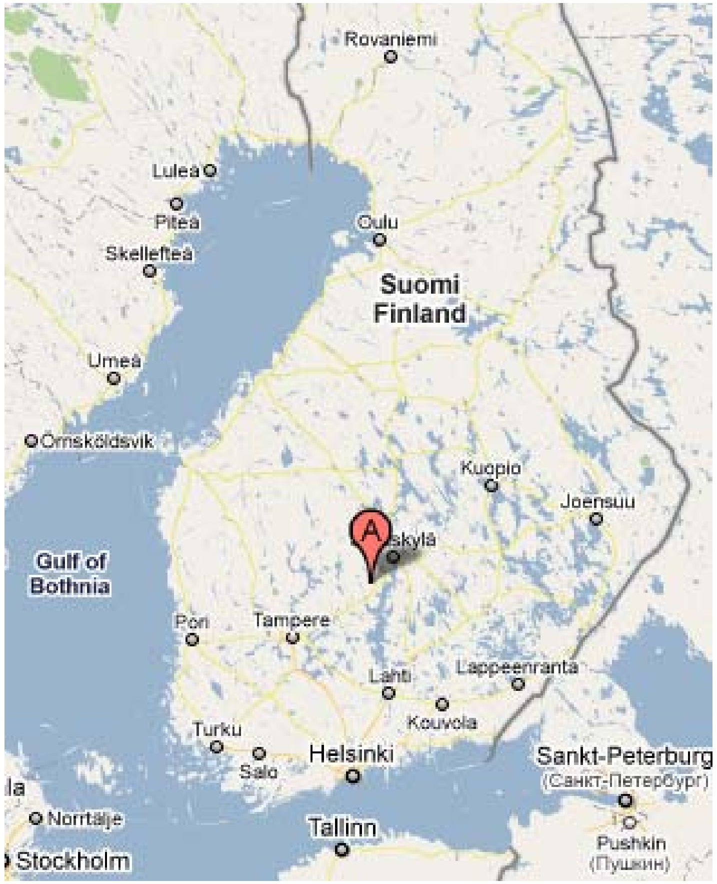
Ehikki-Juokslahti II, reducing permanent deformations by improving drainage

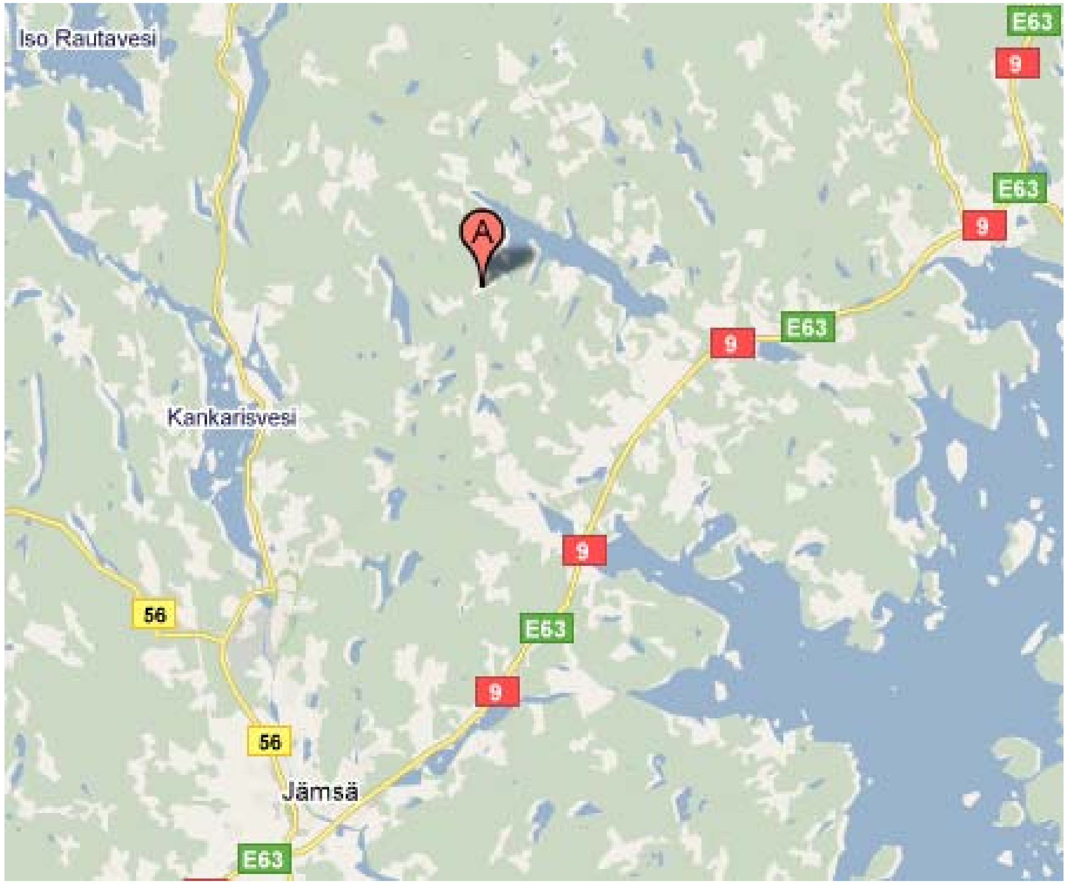
Ehikki-Juokslahti II, reducing permanent deformations by improving drainage

Ehikki-Juokslahti II, drainage improvement structure after the first winter

Ehikki-Juokslahti II, drainage improvement 'reference' structure

Ehikki-Juokslahti III, reinforcement of a Mode II rutting site on peat subgrade





Ehikki-Juokslahti III, reinforcement of a Mode II rutting site on peat subgrade

Mode II rutting and related widening of the road cross section on a peat area - poor drainage due to inoperative outlet ditch.

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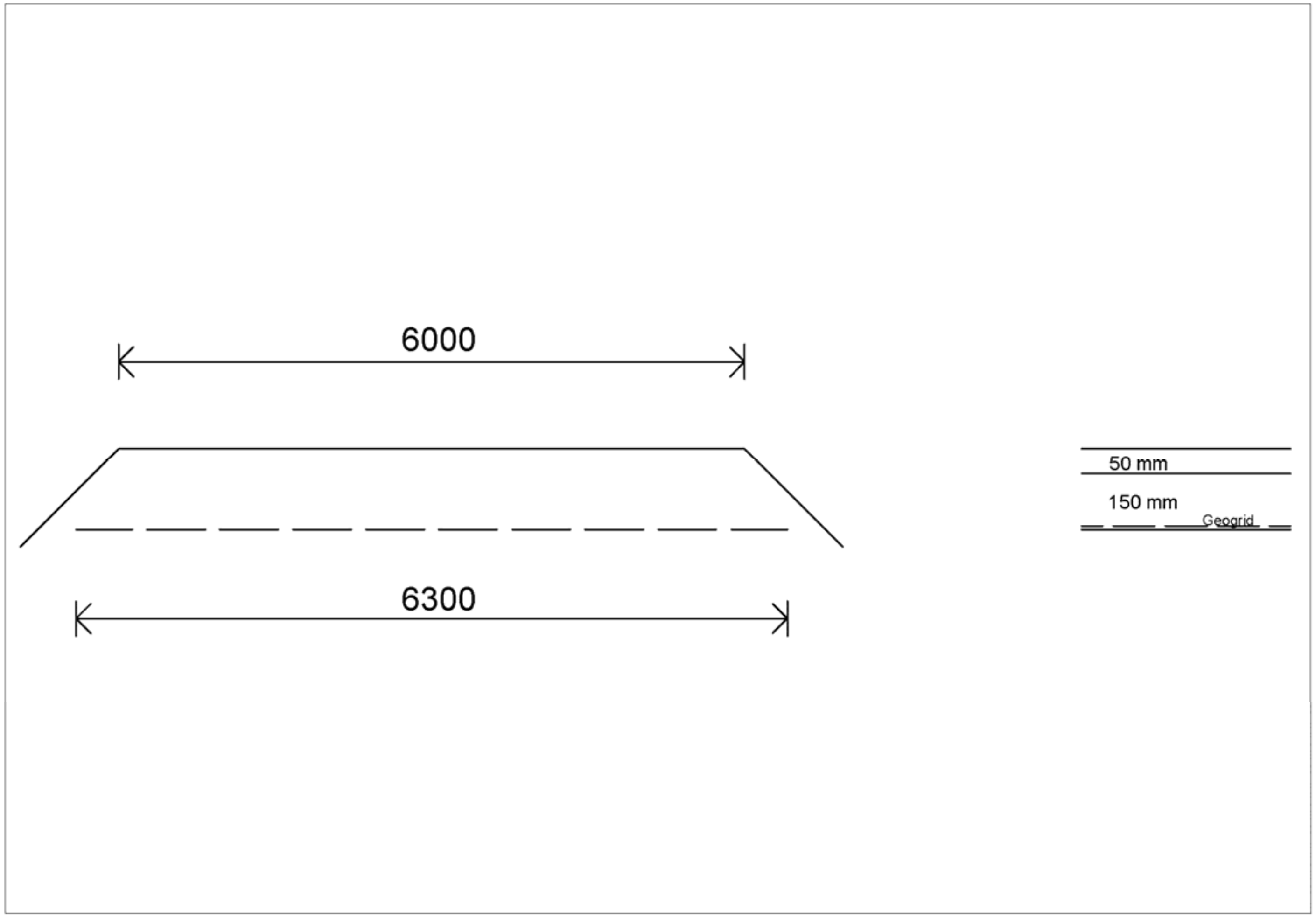
Ehikki-Juokslahti III, reinforcement of a Mode II rutting site on peat subgrade

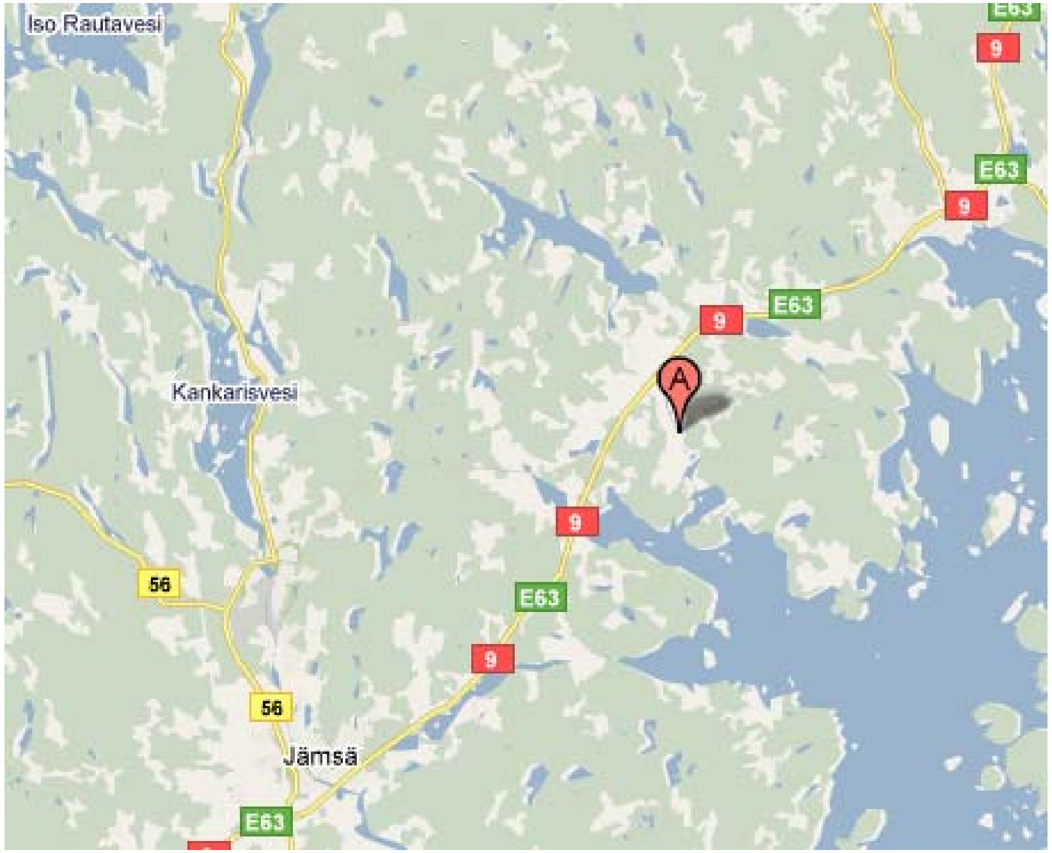


Ehikki-Juokslahti III, reinforcement of a Mode II rutting site on peat subgrade

Ehikki-Juokslahti III, reinforcement of a Mode II rutting site on peat subgrade

Ehikki-Juokslahti III, Mode II rutting site after the first winter

Saalahti, reinforcement of a Mode II rutting site on a silty subgrade



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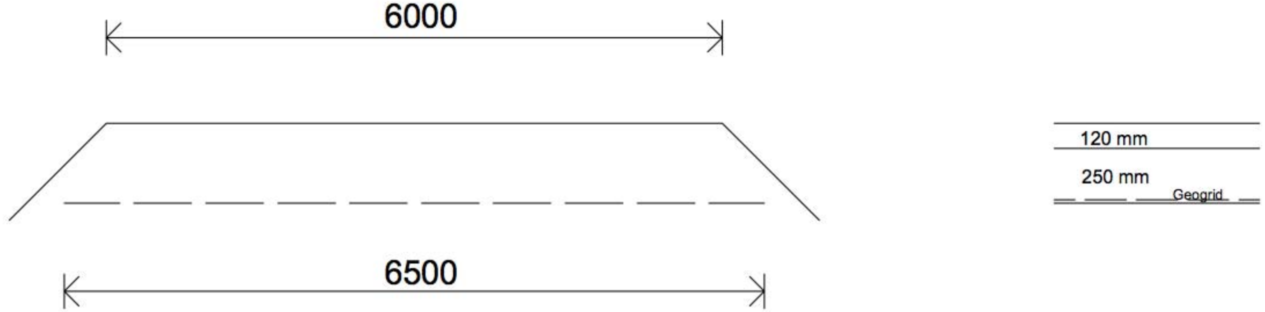
Saalahti, reinforcement of a Mode II rutting site on a silty subgrade

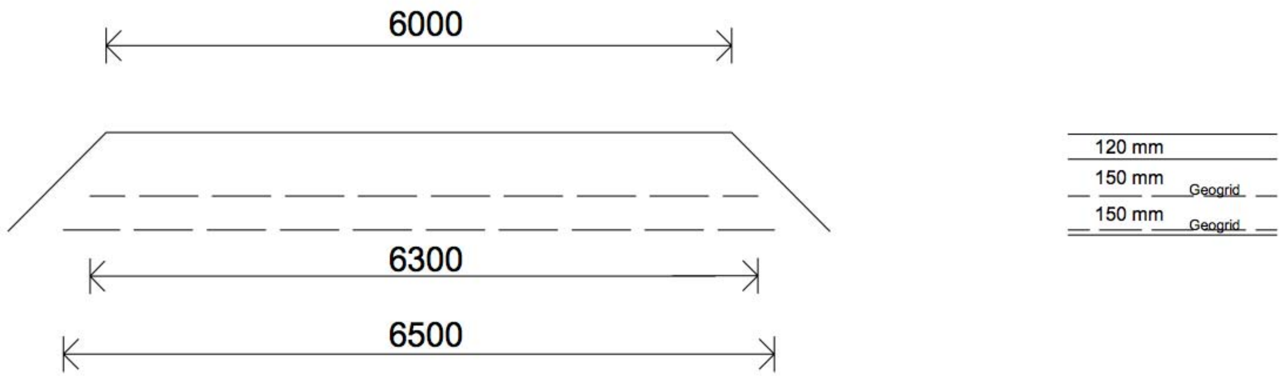
Mode II rutting and related extensive widening of the road cross section on a silty subgrade area - side ditches have practically disappeared.

Saalahti, reinforcement of a Mode II rutting site on a silty subgrade

1B



1C



Saalahti, reinforcement of a Mode II rutting site on a silty subgrade

Saalahti, reinforcement of a Mode II rutting site after the first winter

Saalahti, typical drainage problems of the area one year after ditch cleaning

Summary of the permanent deformation demonstration sites in Jämsä area

- All of the test structures were observed to be in very good condition after the first winter period
- Settlement tubes didn't indicate any marked deformations in the cross sections so far
- Reports on all of the four test sites now available at: www.roadex.org
- Next monitoring cycle of the sites in spring/early summer 2012 → concise revising of the reports if required

Summary of the presentation

- New mechanistic design approach for Low Volume Roads has been suggested
- In low budget projects determination of the input parameters for the mechanistic design remains a challenge
- After all, everything is based on correct problem analysis/diagnosis, sound understanding of the distress mechanisms and fit-for-purpose rehabilitation solutions
- Finally, remember always to keep drainage operative

Questions ?