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# Modeling the loading behavior of railway structure under static load


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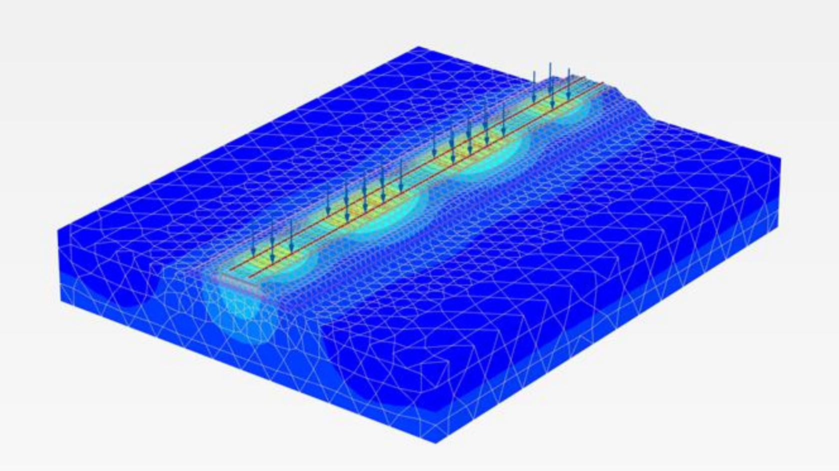
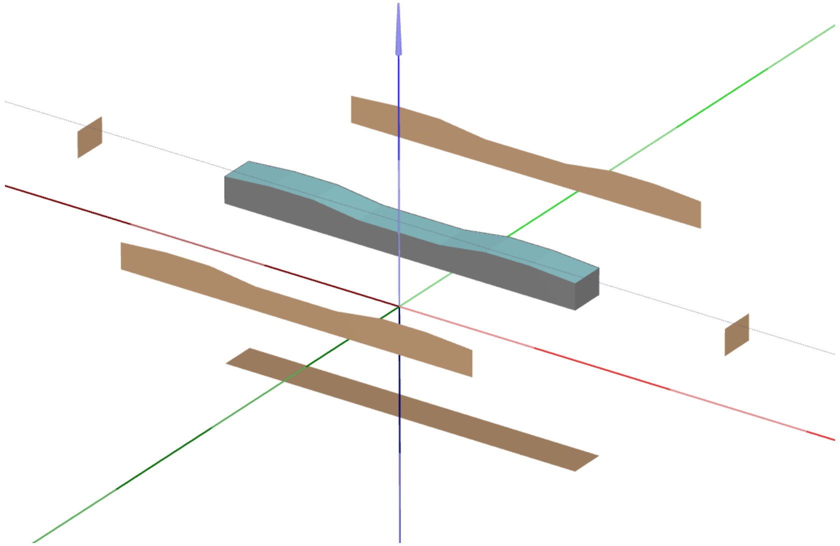
# 3D finite element model to describe the loading behavior of railway structure under static loading

- The aim has been to create and verify a non-linear 3D FE-model to describe the stress-strain response of a railway structure under static loading.
- Full scale 3D FE-model is created using Plaxis 3D software (version 2017). The model is verified using measured field data from two heavily instrumented test structures.
- Elasto plastic Hardening Soil material model has been used for all granular layers of the structure. For the subgrade and superstructure components a linear elastic material model has been used.
- The rails are modelled using beam elements (parameters correspond to the 60E1 rail profile). The geometry of the modeled sleepers is based on the geometry of the B97 concrete sleeper with certain simplifications - all sides of the sleeper are separated from the surrounding ballast layer by interface elements (a picture at right).





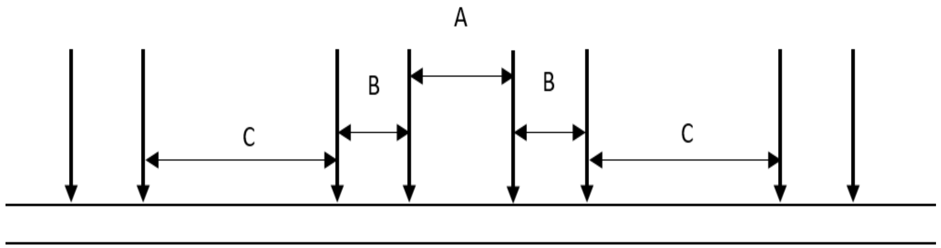
# Calculation parameters and loading diagrams

Material parameters used in FE-models:

| | y | E | E_oed | E_ur | v_ur | m | c' | ϕ | φ | R_f | K_0 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | [kN/m^3] | [MPa] | [MPa] | [MPa] | [-] | [-] | [kPa] | [°] | [°] | [-] | [-] |
| **Koria-Kouvola-model** | | | | | | | | | | | |
| **New ballast** | 17 | 420 | 420 | 840 | 0,2 | 0,65 | 5 | 53 | 18 | 0,5 | 0,35 |
| **Old ballast** | 18 | 400 | 365 | 800 | 0,2 | 0,7 | 4 | 50 | 17 | 0,5 | 0,35 |
| **Coarse sand** | 20 | 270 | 270 | 540 | 0,2 | 0,35 | 4 | 44,5 | 13 | 0,6 | 0,37 |
| **Gravel** | 19,5 | 475 | 475 | 950 | 0,2 | 0,5 | 3 | 51 | 17 | 0,55 | 0,35 |
| **Pori-Mäntyluoto-model** | | | | | | | | | | | |
| **Ballast layer** | 17 | 380 | 380 | 760 | 0,2 | 0,6 | 6 | 52 | 18 | 0,5 | 0,35 |
| **Fine sand** | 19,5 | 240 | 240 | 480 | 0,2 | 0,5 | 1 | 37 | 6 | 0,6 | 0,40 |

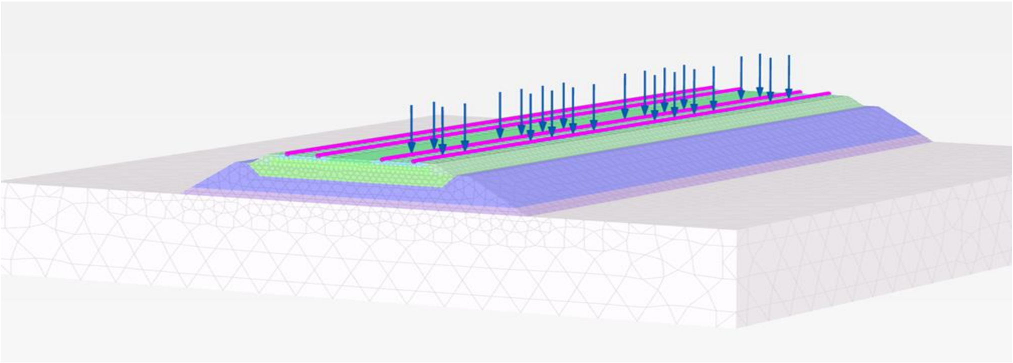
Loading diagram dimensions used in calculations:

| | A [m] | B [m] | C [m] |
|---|---|---|---|
| **Koria-Kouvola-model** | 1.8 | 1.8 | 5.4 |
| **Pori-Mäntyluoto-model** | 1.8 | 1.77 | 8.55 |

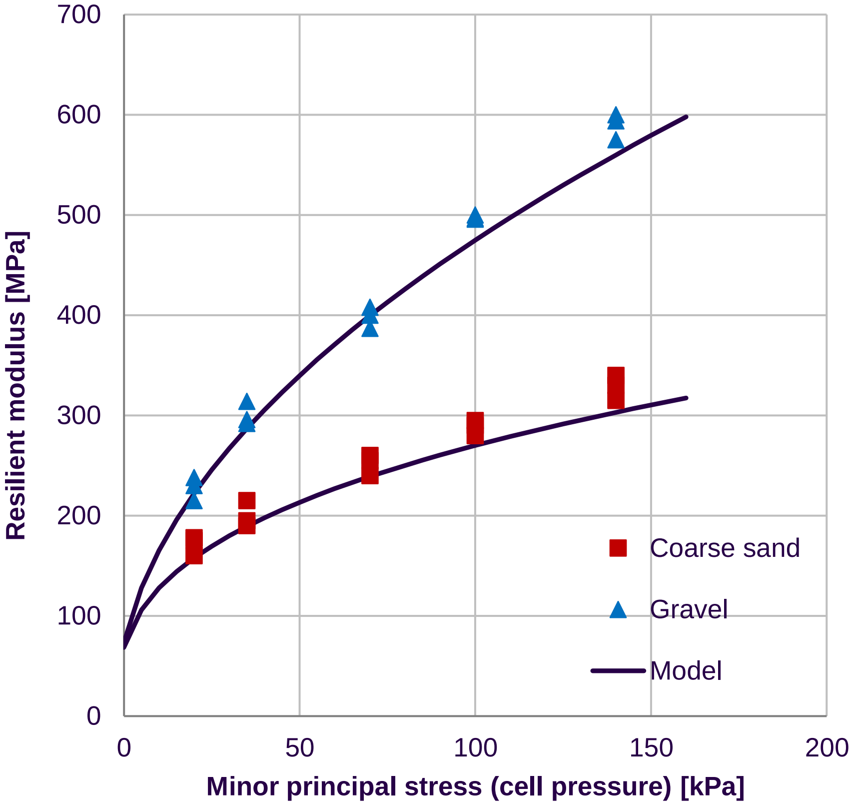


# Koria-Kouvola verification model

- Structure is characterized by a thick ballast layer with a total thickness of 1.2 meters. The substructure consists of a 0.8 meters thick coarse sand layer and a 0.4 m thick gravel layer.
- The subgrade thickness of the model is 5 meters, and its modulus of elasticity has a constant value of 56 MPa. The FE-model have about 500 000 elements.
- The calculation parameters of the substructure layers are based on the laboratory test results.
- Sensors measuring stress and strains are placed at different depths in the structure. Also, the vertical displacements have been measured at three different points from the sleeper.

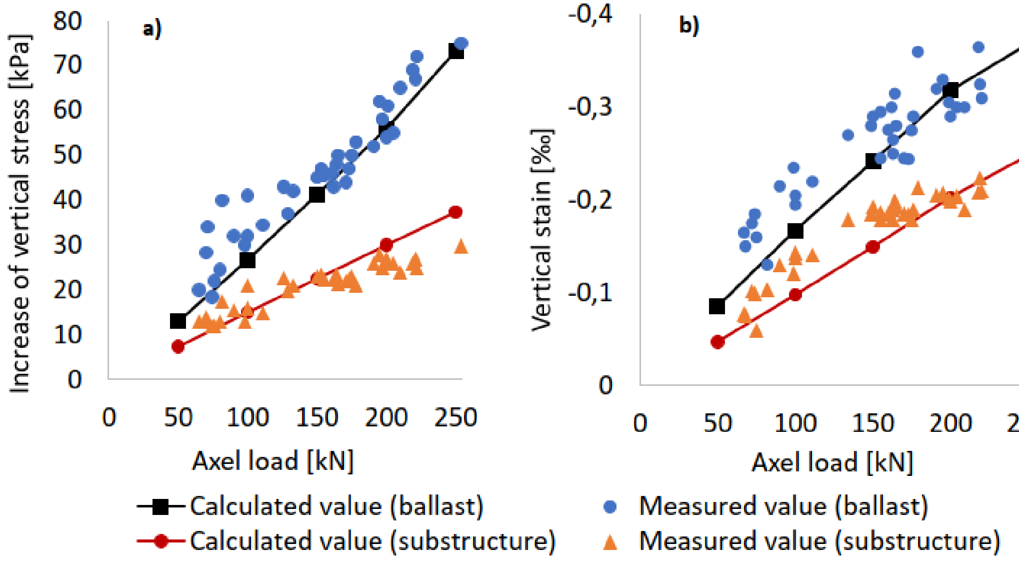


Calculated and measured resilient modulus with different cell pressures:



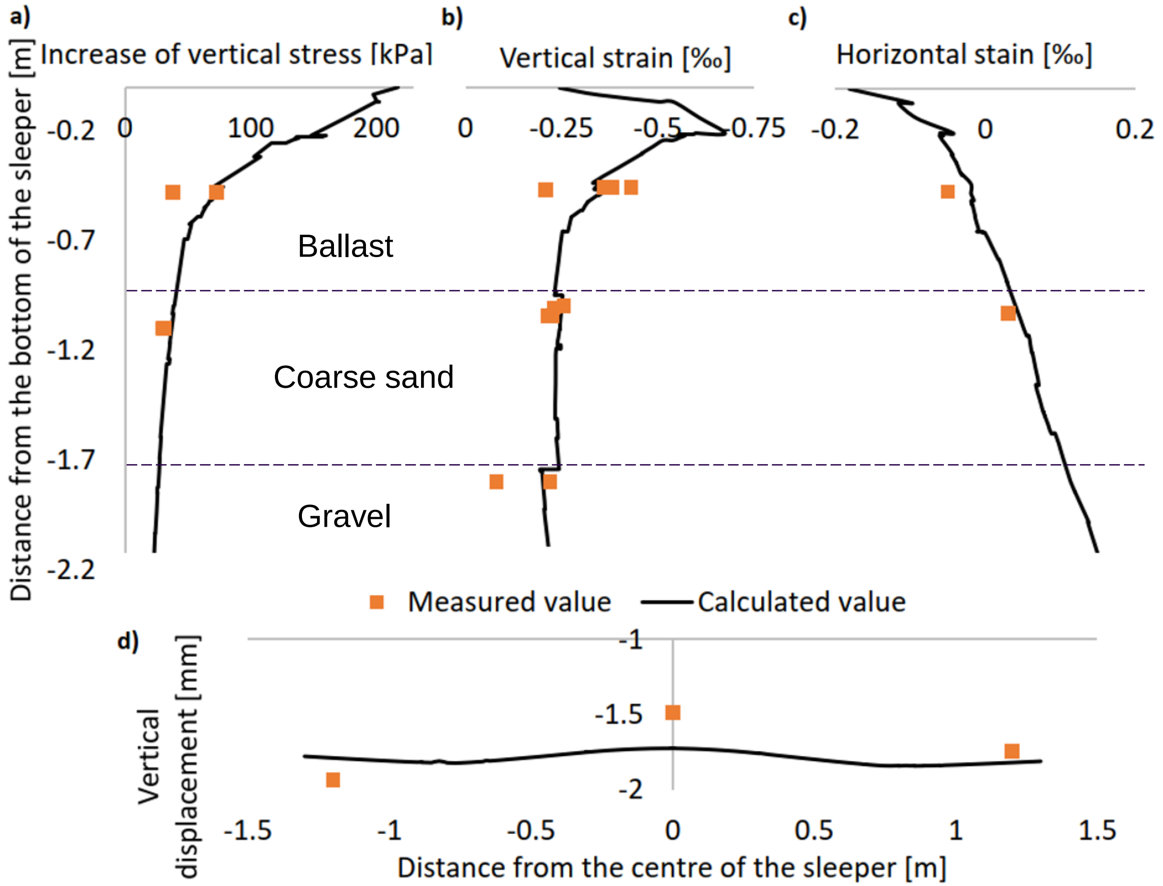
# Verification calculation results compared to Koria-Kouvola measurements

Effect of axel load:




→ The influence of the axel load seems to be fairly linear

Calculated and measured stresses, strains and sleeper displacements under 250 kN axel load:



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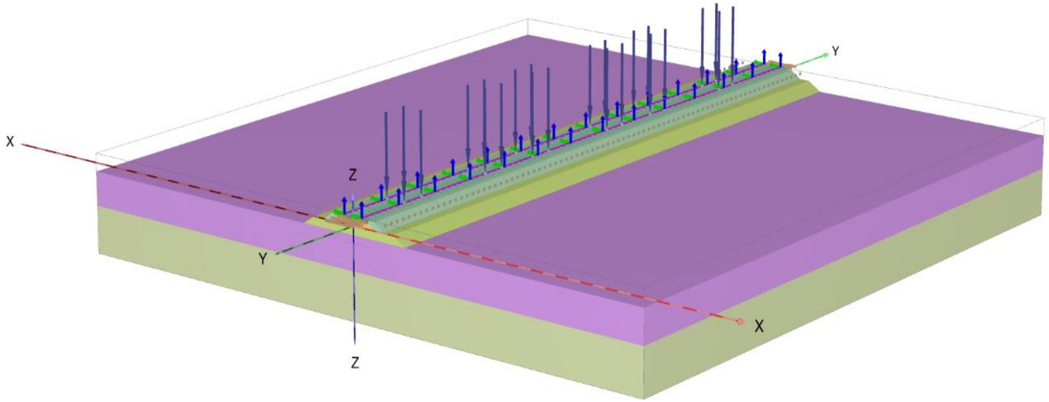
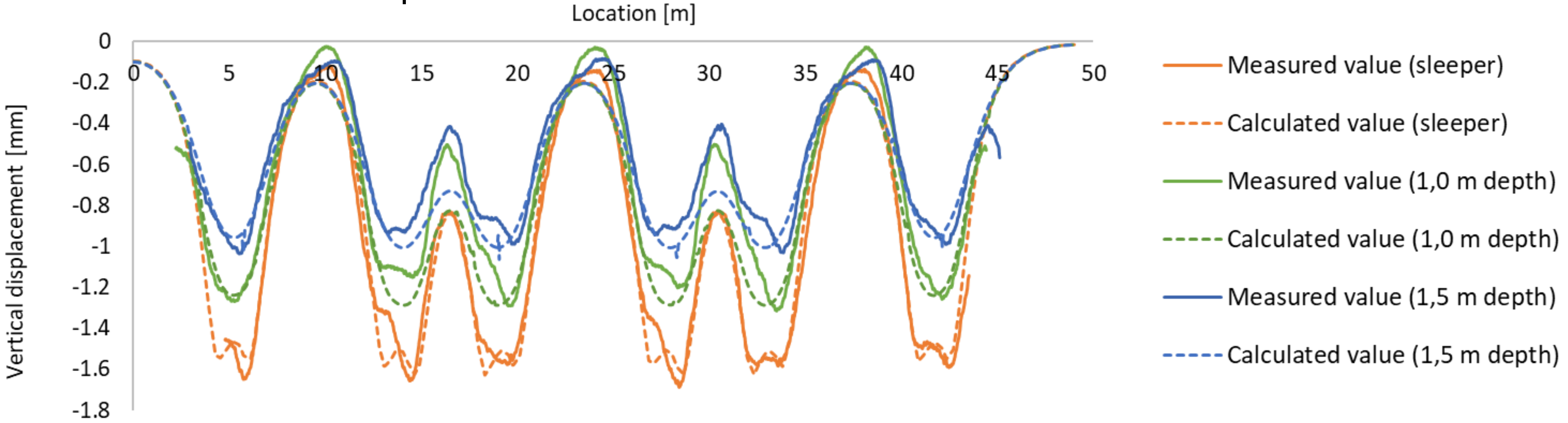



# Pori-Mäntyluoto verification model

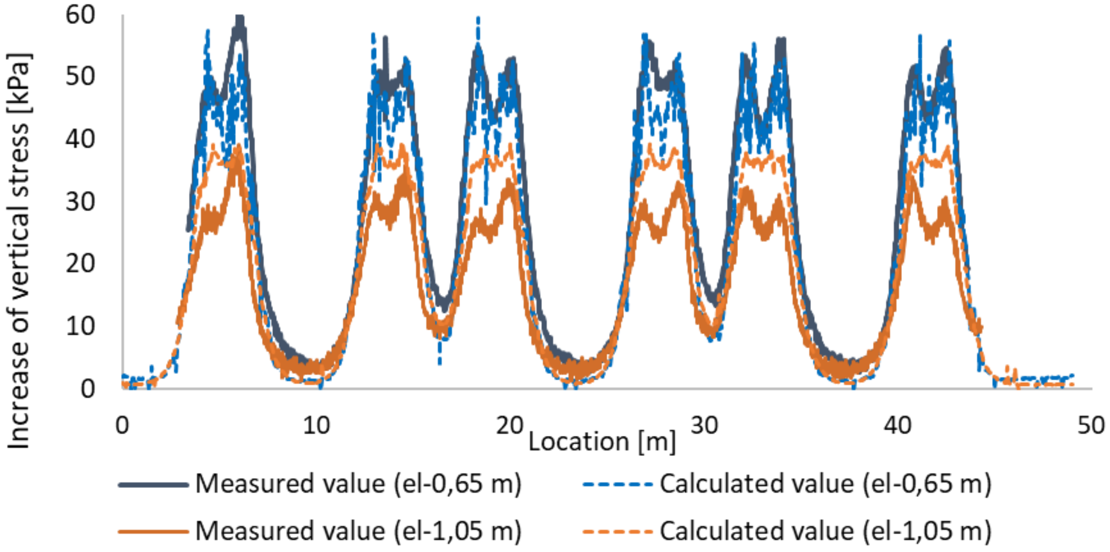
- A single-track section with a total thickness of 1.1 meters (the ballast layer is 0.5 meters thick, and the substructure consists of a 0.6-meter-thick fine-grained sand layer). The FE-model is 48.8 m long and 30 m wide and it have about 350 000 elements.
- Vertical, longitudinal, and transverse earth pressures have been measured below the sleeper from two different depths (0.4 and 0.7 meters from the bottom of the sleeper). Also, the vertical displacements of the structure have been measured from three different depths; from the top of the sleeper, elevation line (el.) -1.0 m and elevation line -1.5 m.
- The subsoil is divided into two layers; to 2.2 m thick clay layer with an initial modulus of 50 MPa and a lower 3-meter-thick sand layer with an initial modulus of 100 MPa. The stiffness of the subsoil layers is assumed to increase linearly with respect to dept.

# Pori-Mäntyluoto: verification calculations (axel load 208 kN)

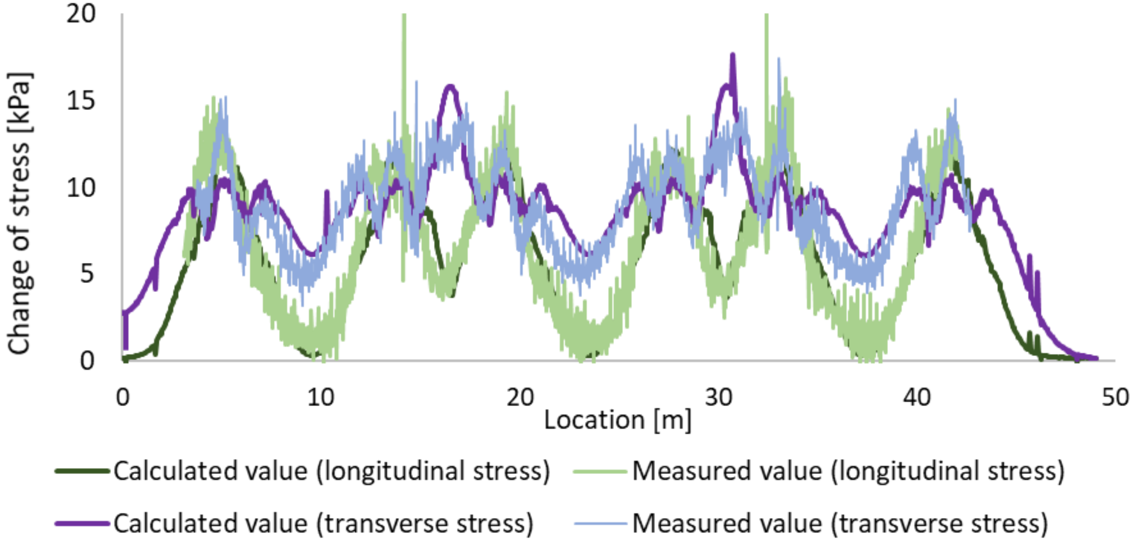
Vertical displacements at different depths:




Increase of vertical stress at different depths:




Longitudinal- and transverse stress increases:



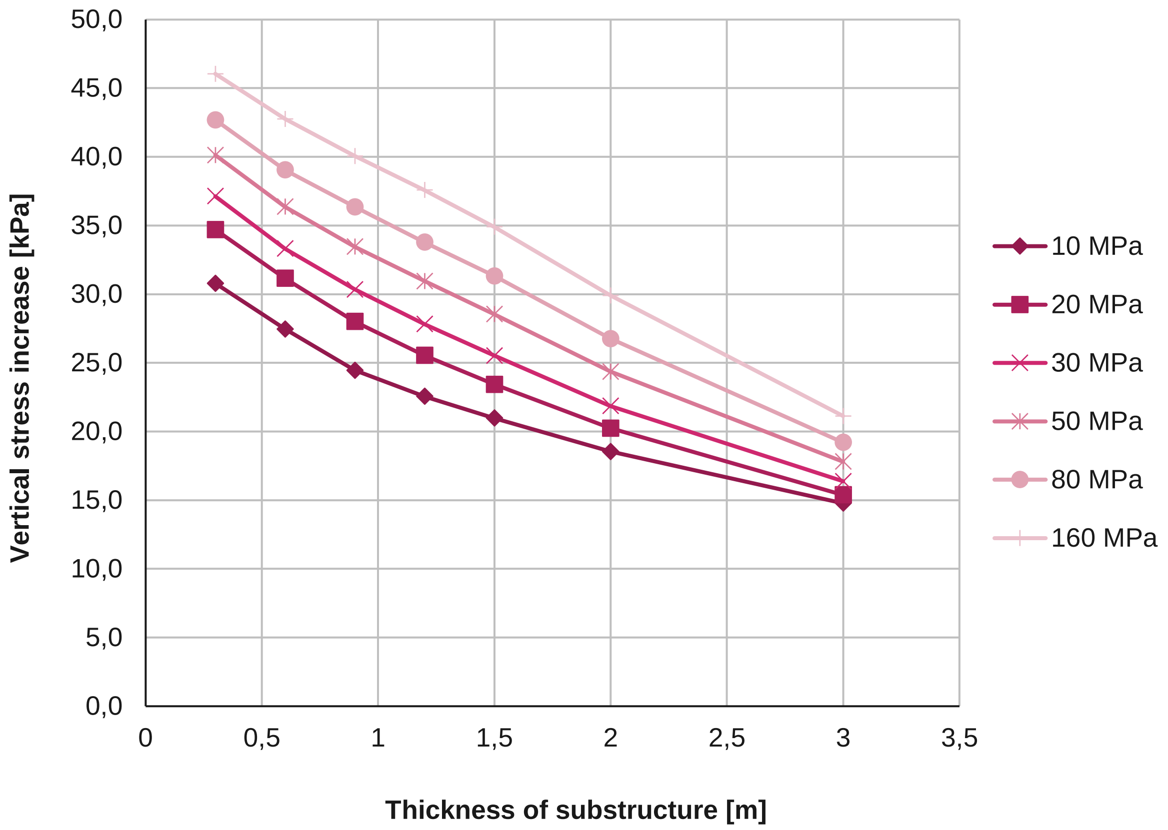
# Structural variation calculations

- The purpose is to determine the effect of various factors on the load response of the track structure at a principal level
- Subgrade stiffness and thickness as well as substructure thickness and material quality are treated as variables.
- Six different subgrade stiffnesses has been used (10, 20, 30, 50, 80 and 160 MPa) - the thickness of the subgrade is five meters in most of the calculations.
- The thickness of the substructure varies between 0.3 and 3 m (the substructure material is coarse sand, unless otherwise stated). The calculation parameters are quite similar than ones used in verification models and are based on the literature:

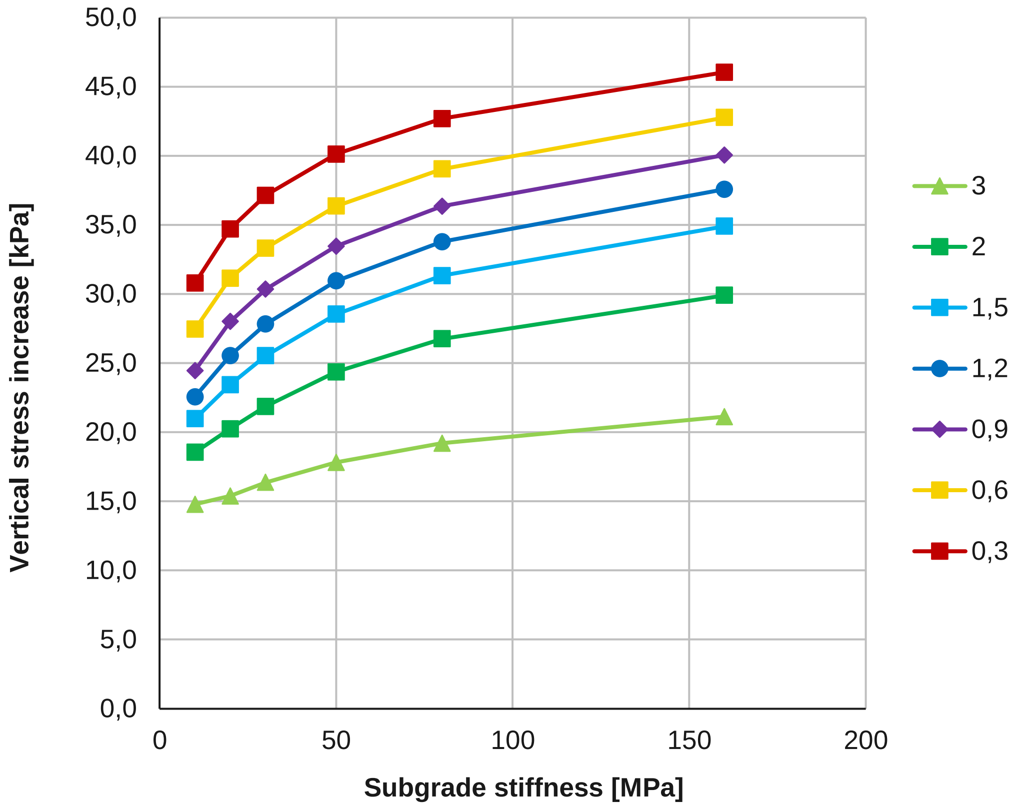
| Material | y | E | E_oed | E_ur | v_ur | m | c' | ϕ | φ | R_f | K_0 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | [kN/m^3] | [MPa] | [MPa] | [MPa] | [-] | [-] | [kPa] | [°] | [°] | [-] | [-] |
| **Ballast** | 17 | 380 | 380 | 760 | 0,2 | 0,6 | 6 | 52 | 18 | 0,5 | 0,35 |
| **Open-Graded Aggregate** | 19,5 | 300 | 300 | 600 | 0,2 | 0,5 | 2 | 48 | 15 | 0,55 | 0,37 |
| **Coarse Sand** | 19,5 | 280 | 280 | 560 | 0,2 | 0,5 | 2 | 42 | 10 | 0,55 | 0,37 |
| **Fine Sand** | 19,5 | 260 | 260 | 520 | 0,2 | 0,5 | 1 | 36 | 6 | 0,55 | 0,41 |

# Vertical stress increase top of the subgrade (axel load 250 kN)

Effect of subgrade stiffness as a function of substructure thickness:




Effect of substructure thickness (m) as a function of subgrade stiffness:



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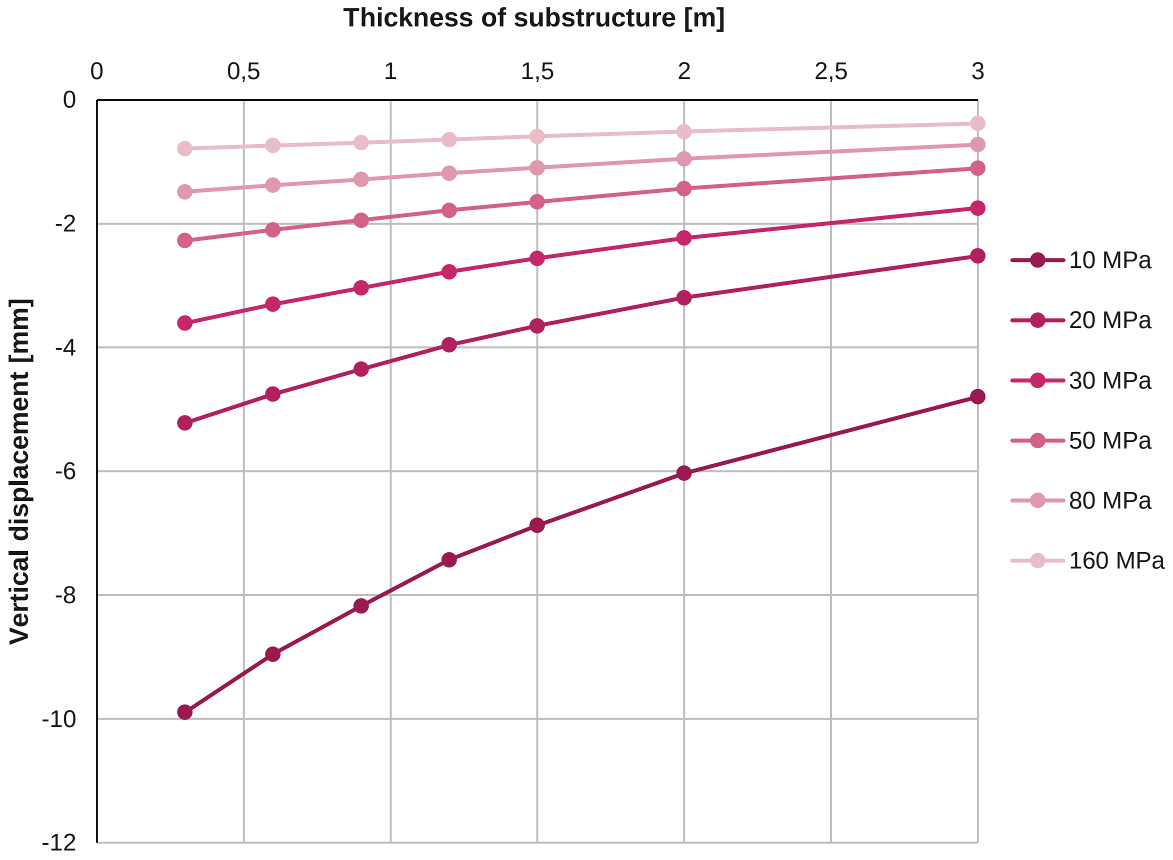
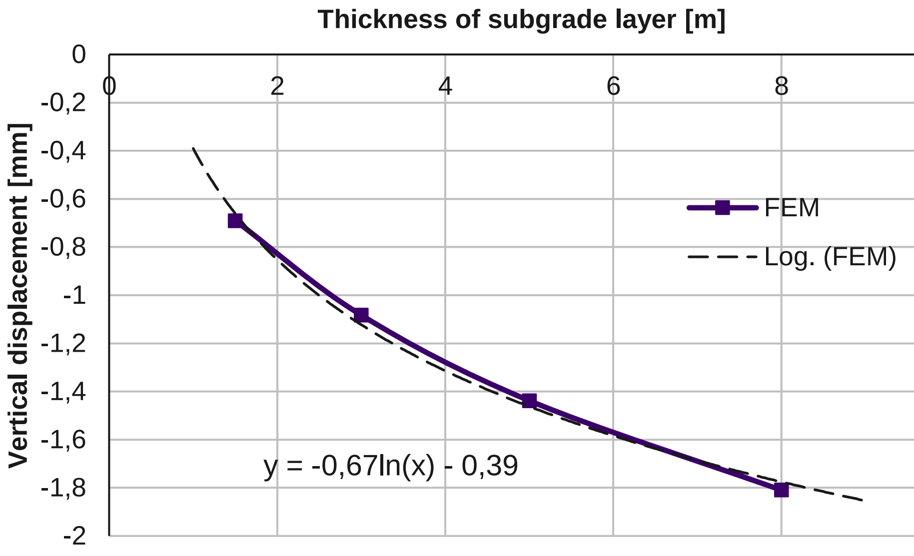
# Vertical displacements of the subgrade (axel load 250 kN)

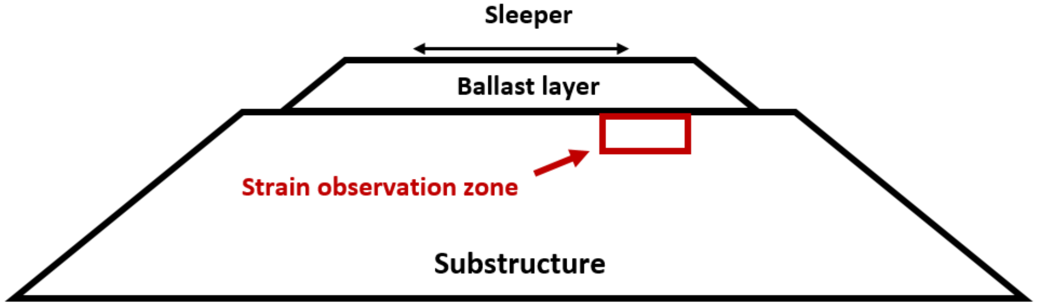
Effect of subgrade stiffness (with constant thickness of 5 m) and substructure thickness:



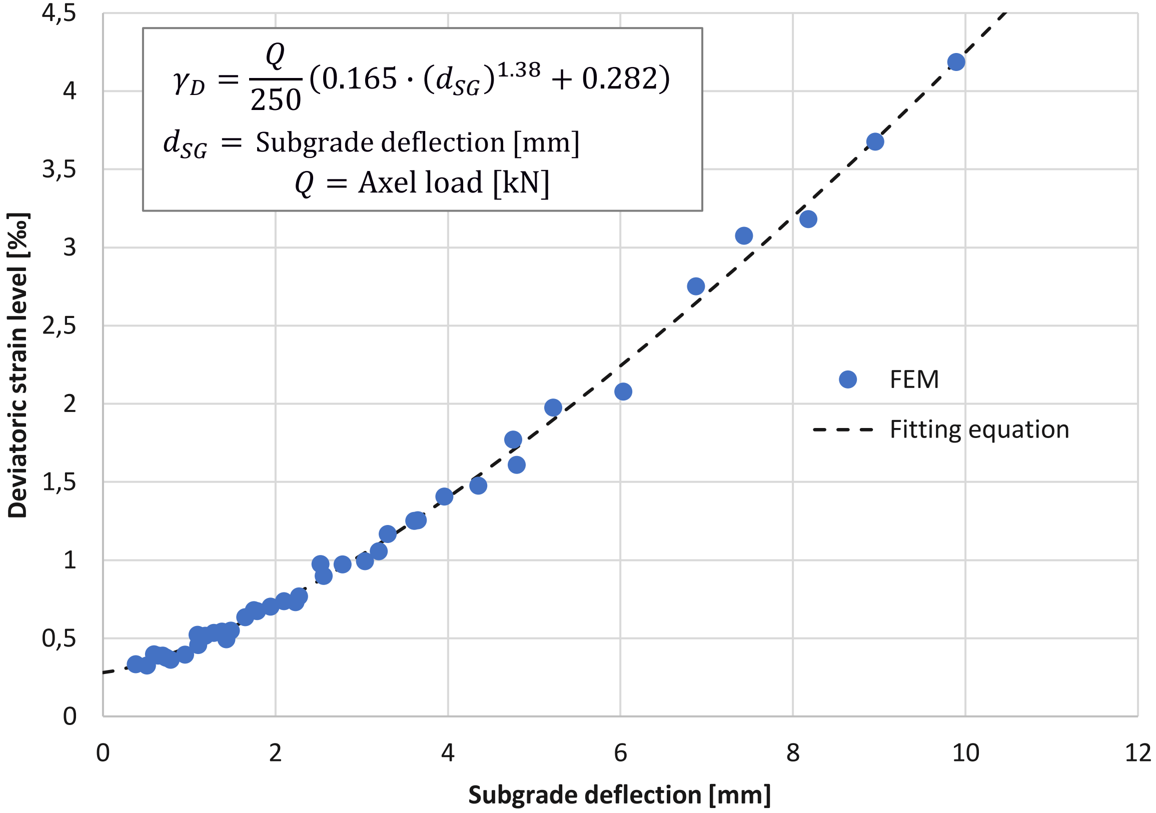

Effect of subgrade thickness (constant modulus 50 MPa, substructure is 2 m thick):



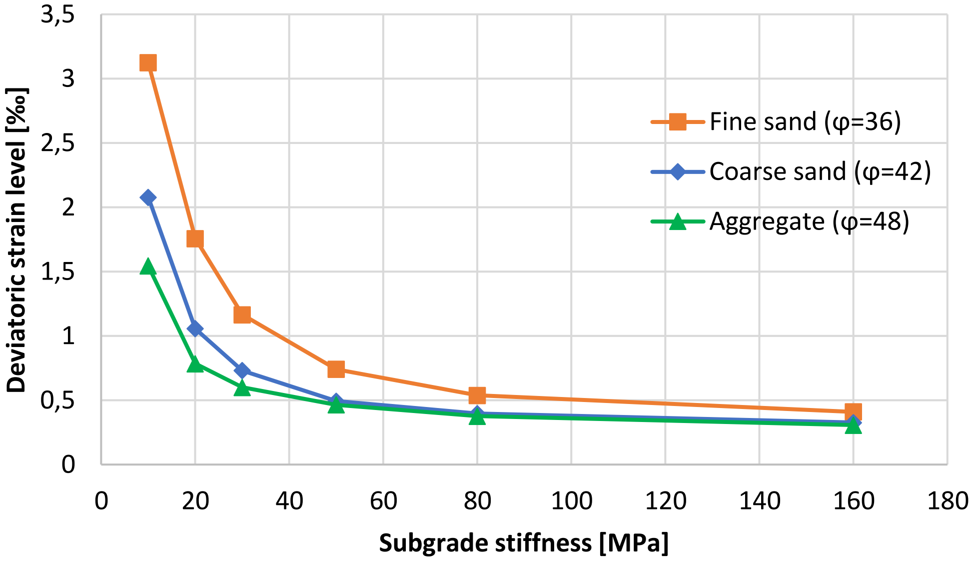
# Deviatoric strain levels in upper substructure (axel load 250 kN)




Effect of subgrade deflection level (substructure material is coarse sand):




Effect of substructure material quality:



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# Conclusions

- Based on the verifications, the model seems to corresponds very well to the test structures in its behavior.
- The effect of axle weight on the resilient behavior of the structure appears to be quite linear – however, the influence on the plastic deformation behavior is probably more non-linear.
- The subgrade stiffness seems to be the most important factor in terms of the deviatoric strain levels of the structure; on flexible subgrades, the deformations are typically large throughout the structure.
- The higher the substructure material quality is, the lower it's strain levels typically are on weak subgrades.