Transition zone design for reduced track settlements

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Outline

- Description of the problem
- Slab track design “3MB”
- Iron ore vehicle model
- Non-linear track model
- Iterative approach to predict settlement in a transition zone
- Influence of axle load
- Field measurement
- Conclusions
- Future work

Transition zone

Between different superstructures, e.g. slab track to ballasted track, and/or between different substructures, e.g. embankment to a bridge or tunnel

Problems

- Stiffness gradient, leading to increased wheel-rail contact force
- Accumulated permanent deformation of ballast and soil
- Hanging sleepers
- Influence on passenger comfort and increased maintenance effort to restore track geometry

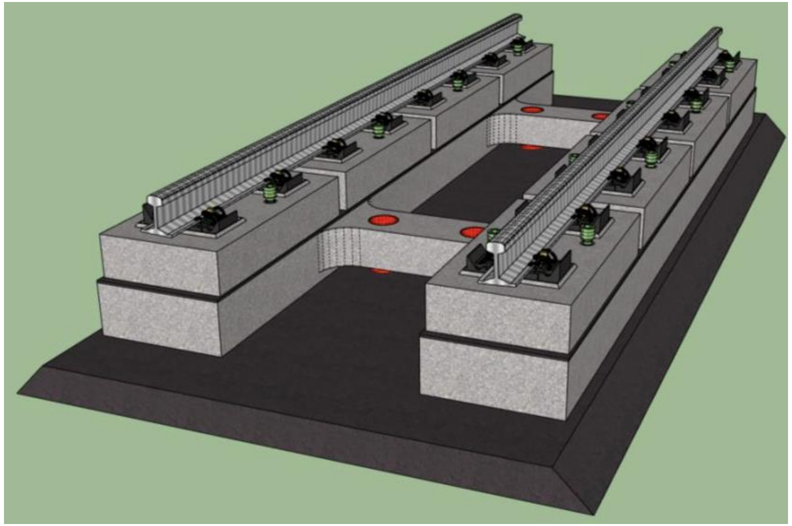
Solutions

- Approach slab to gradually change track stiffness
- Gradually varying sleeper length and spacing
- Under sleeper pads and slab pads
- Auxiliary rails, etc.

From: Sañudo et al., *Construction and Building Materials*, 112, pp 140–157, 2016

Slab track design “3MB”

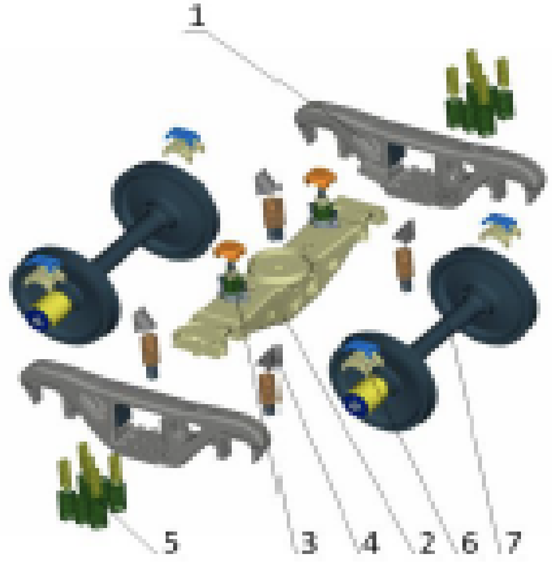
- A concept of multiple-level modularity
- Two longitudinal reinforced concrete beams (base slab)
- Eight pre-casted and moulded concrete blocks
- A double steel piston system (steel pins) to restrain the moulded blocks horizontally
- Two non-coaxial steel connectors to prevent rotation around the piston axis
- Elastomeric strips provide vibration attenuation and prevent hammering between base slab and blocks



From Morales-Gamiz, F. J.: Design requirements, concepts and prototype test results for new system of ballast less system (3MB slab track), 2017

Vehicle model

- Iron ore wagon used on Malmbanan in north of Sweden
- Fanoo wagons on Amsted Motion Control M976 three-piece bogies with load sensitive frictional damping
- Axle load up to 32.5 tonnes, train speed of loaded train 60 km/h
- Sliding friction between bolster and side frames is modelled by a simplified Coulomb friction model using a tangens hyperbolicus function
- Two-dimensional vehicle model with car body (including bolsters), two side frames and four wheelsets, primary and secondary suspensions; 10 dofs

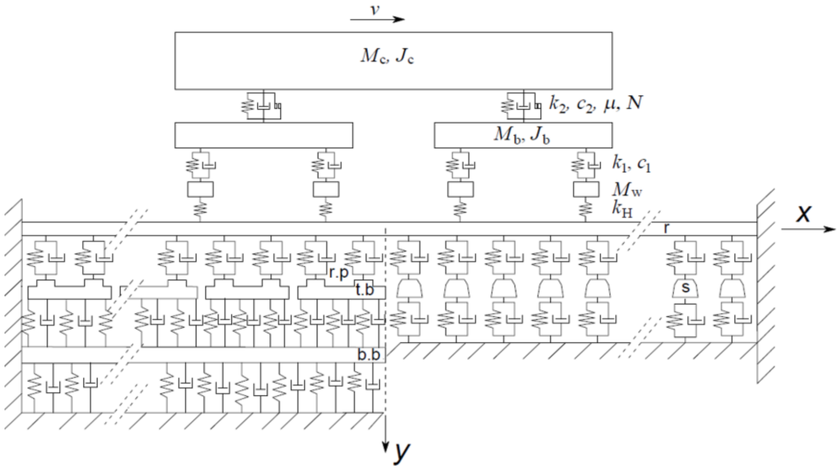


Three-piece bogies 1-side frame, 2-bolster, 3-side bearers, 4-wedge, 5-coil spring in suspension system, 6-adapter, 7-wheelset.

From Bogojevic et al., *Heavy Machinery*, June, pp 39–44, 2011

Non-linear track model

- Track length: 60 m (42 m ballasted side, 18 m slab side)
- Rail, blocks and base slab are modelled using Euler-Bernoulli beam theory
- The connection between each pair of adjacent nodes in the different layers is modelled by a spring and viscous damper



- The base slab is supported by a viscously damped Winkler foundation
- Each (rigid) sleeper is supported by a discrete spring and viscous damper (Kelvin model). Piecewise linear stiffness to account for hanging sleepers. Nonlinear F-Δ is also considered.
- Gravity load is considered
- An initial (lower) level of the ballast surface to account for consolidated ballast can be specified

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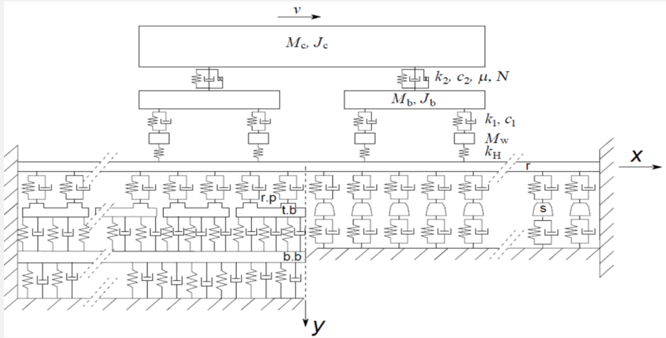
Iterative approach to predict settlement at transition zones

Initial track model

Track displacement due to gravity load

Dynamic vehicle-track interaction



For each sleeper

Sleeper-ballast force (maximum per wheelset passage)

Settlement increment

Accumulated settlement

Update threshold value and ballast/subgrade stiffness in track model

Settlement model

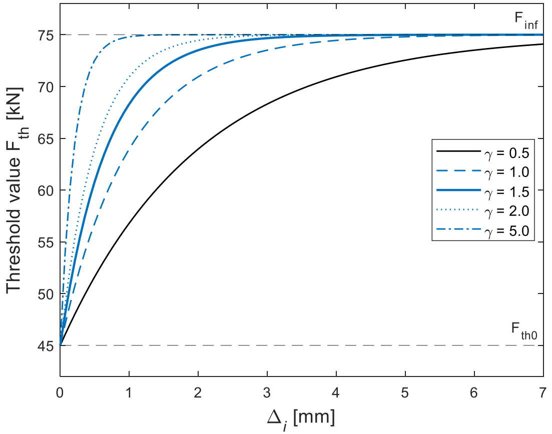
- Empirical settlement model based on a visco-plastic material mechanics approach
- Settlement increment per sleeper and iteration step

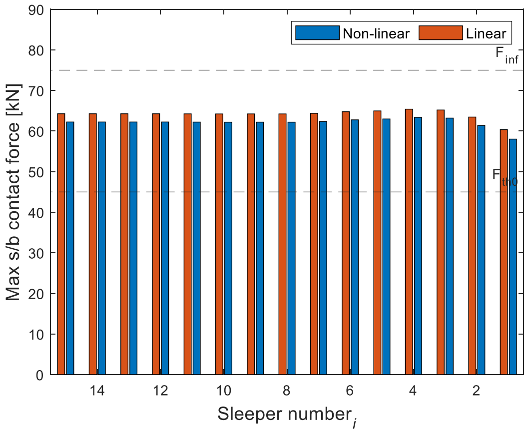
$$\delta_{i,j} = \sum_{n=1}^{N_\mathrm{w}} \left\{ \sum_{k=1}^{N_k} \alpha'_k \left[\frac{\langle \max(F_{\mathrm{s/b},i})_n - F_{\mathrm{th},i} \rangle}{F_0} \right]^{\beta_k} \right\}$$

- Settlement increment if sleeper–ballast force exceeds threshold value

$$F_{\mathrm{th},i}(\Delta_i) = F_{\mathrm{th},\infty} - \left(F_{\mathrm{th},\infty} - F_{\mathrm{th},0}\right) e^{-\gamma \Delta_i}$$

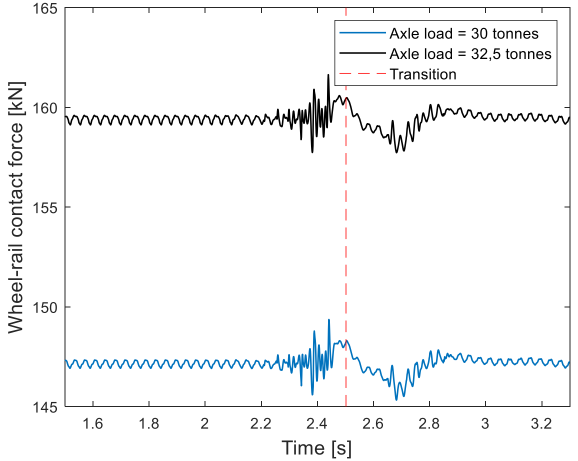
- Hardening parameter γ
- Here: $N_k = 1$, $F_{\mathrm{th},0} = 45$ kN, $F_{\mathrm{th},\infty} = 75$ kN, and $\gamma = 1$.
- Model needs to be calibrated versus field measurements

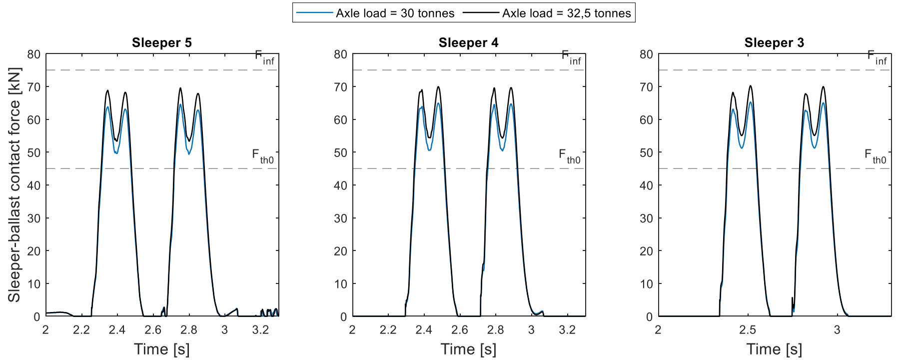




Influence of axle load 1(2)

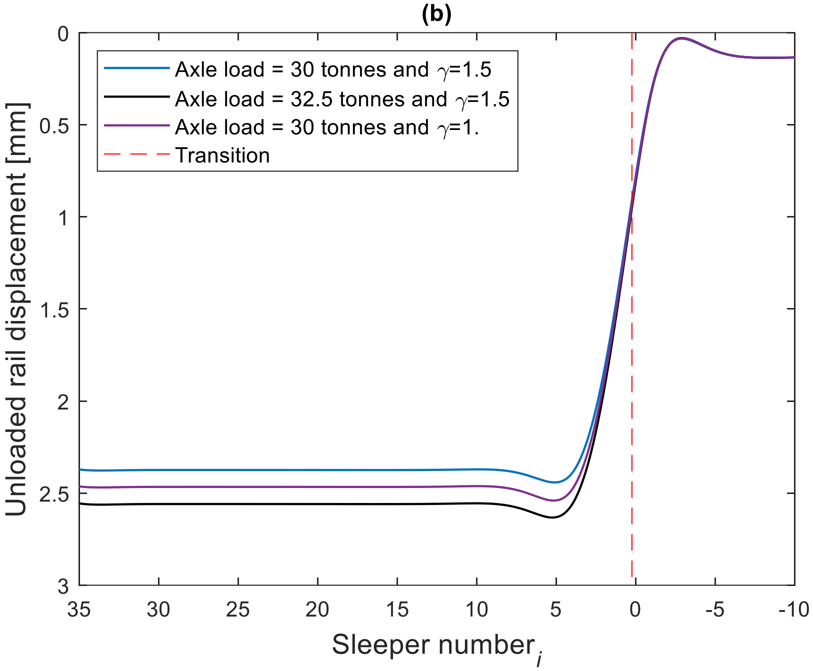
- A uniform 2 mm initial settlement level on the ballasted side has been assumed
- Stiffness gradient leads to a minor contribution to the dynamic load. The influence of the irregularity is more significant
- Increasing axle load leads to increasing sleeper–ballast forces exceeding the threshold value, and thus larger increments of settlement



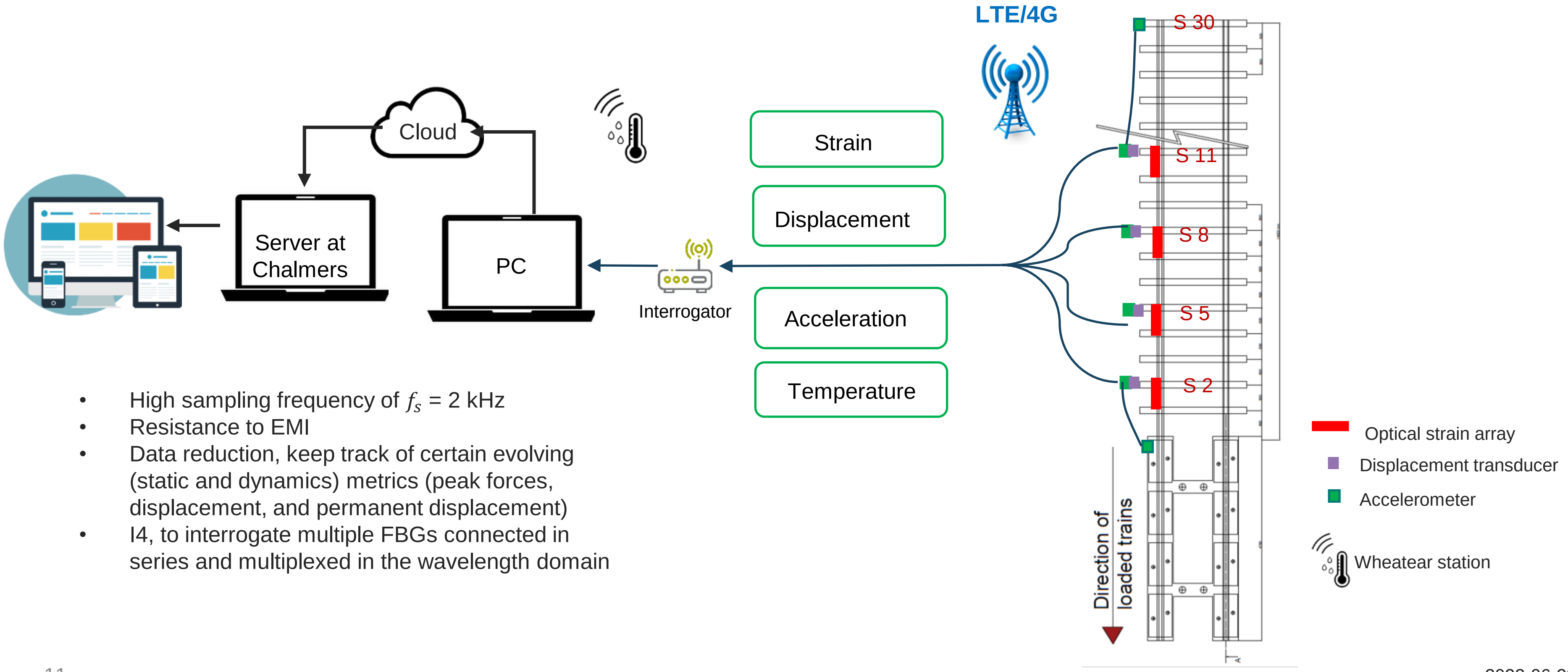


Influence of axle load 2(2)

- Unloaded rail displacement (due to gravity load) along the transition zone after an accumulated traffic load of 45 MGT
- Train speed 60 km/h
- The uniform settlement ahead of the transition and the track irregularity (unloaded rail displacement) at the transition increase with increasing axle load



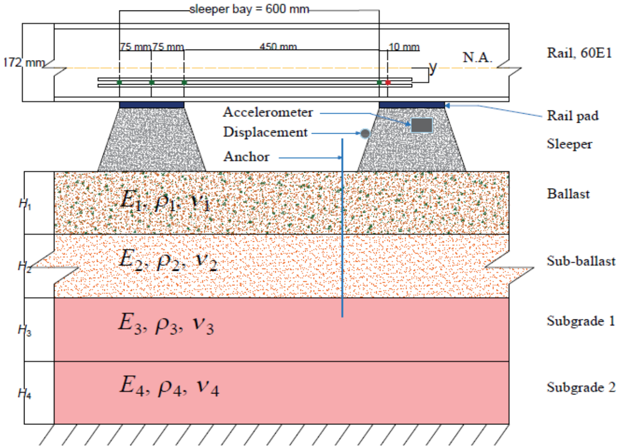
Measurement plan – demonstrator at Gransjö 1(3)

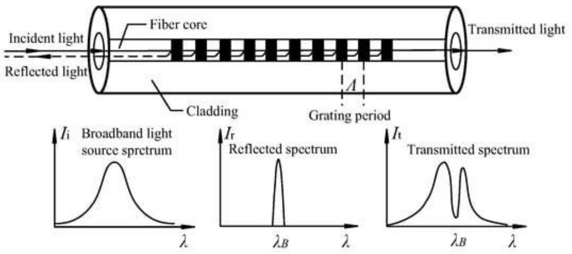


- High sampling frequency of f_s = 2 kHz
- Resistance to EMI
- Data reduction, keep track of certain evolving (static and dynamics) metrics (peak forces, displacement, and permanent displacement)
- I4, to interrogate multiple FBGs connected in series and multiplexed in the wavelength domain

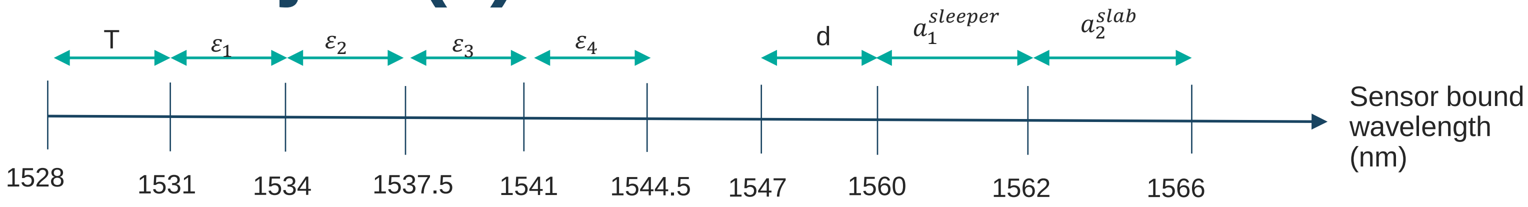
Measurement plan – demonstrator at Gransjö 2(3)

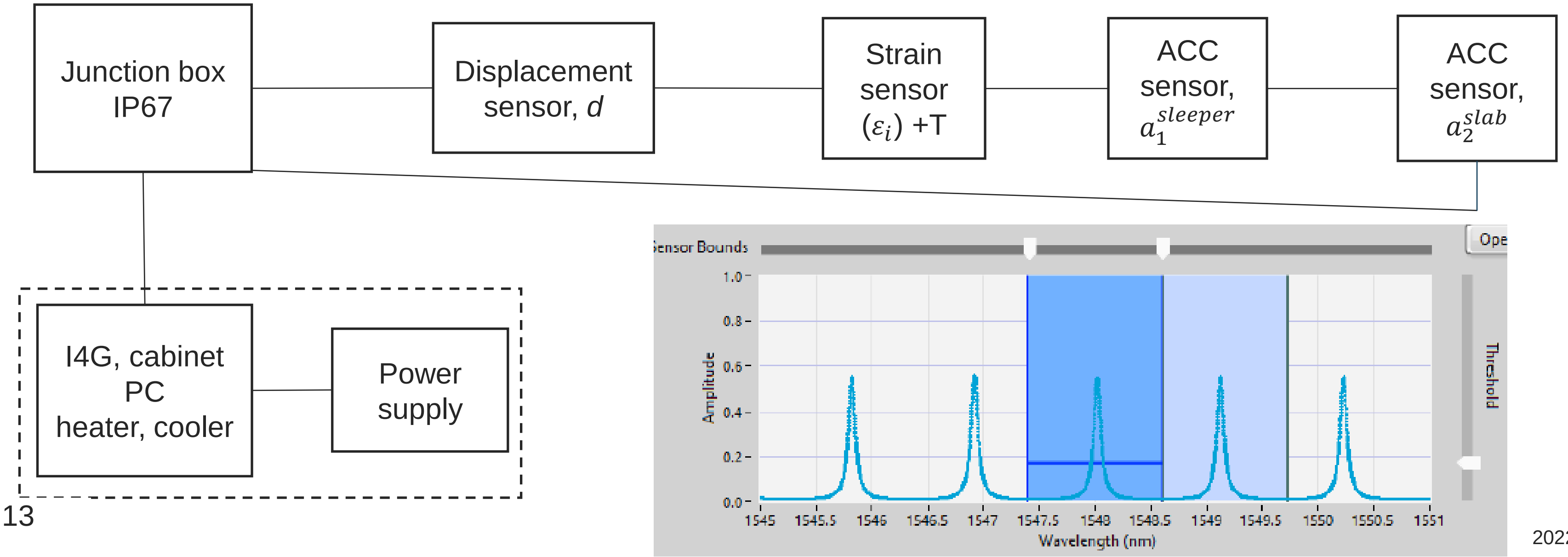
- FBG-based optical sensing system
- Long-term monitoring (approx. 3 years)
- Measure permanent sleeper displacement, range $\pm 50\, mm (res. 30\, \mu m)$
- Operating temperature -20°C to 60°C
- Absolute vertical sleeper acceleration will be measured by an optical accelerometer.
- Measure strain in each sleeper bay by using an array of optical strain gauges to determine wheel–rail contact force and sleeper– ballast forces





Measurement plan – demonstrator at Gransjö 3(3)





Summary of work conducted so far

- We have an iterative procedure for the prediction of long-term degradation of a transition zone between two track forms due to differential settlement of ballast/subgrade
- We have confirmed that the differential settlement of sleepers near the transition is higher than elsewhere
- We have seen the stiffness gradient at the transition leads to a minor contribution to the dynamic load, while the influence of the irregularity is more significant
- The uniform settlement ahead of the transition and the track irregularity (unloaded rail displacement) at the transition increase with increasing axle load
- The uniform settlement was calibrated with available statistics data from Nielsen et al, 2019.

Future work

- Improve and calibrate the model versus field measurements
- Build a three-dimensional model of a transition zone using 3MB slab track model
- Use a cycle domain constitutive model to determine accumulated plastic (permanent) deformation of the layers supporting the track

Thank you for your attention