Reduction of rapid variations in track stiffness around e.g. bridges and tunnels

Presentation to Train Track Interaction, UIC

Proposal based on a Feasibility Study
At LTU and Chalmers, Sweden

Malaga 18th of September 2025
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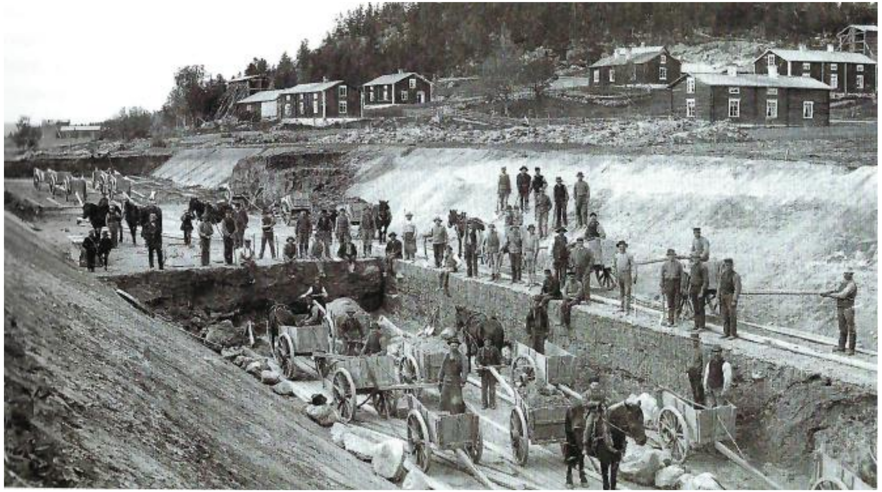
Background – old track

Many of today's railway substructures are often old and built with local materials

Malmbanan is a good example. Here we have found everything from peat to rock cuttings



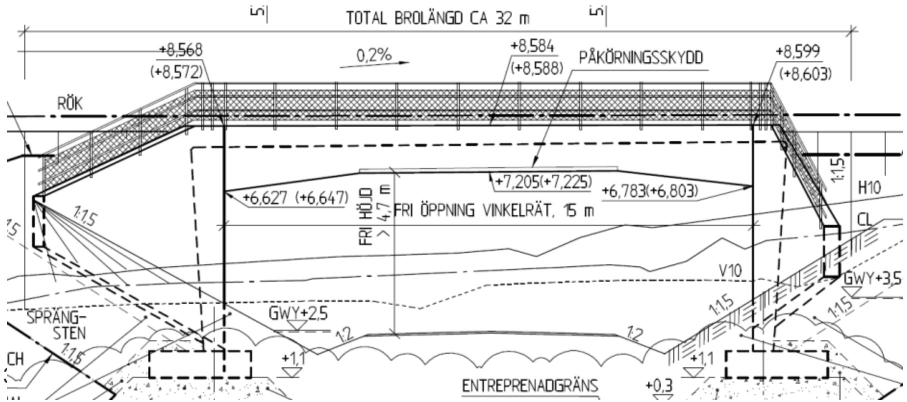
Already at the beginning of the 20th century, a significant part of the Swedish railway network was expanded as single track.

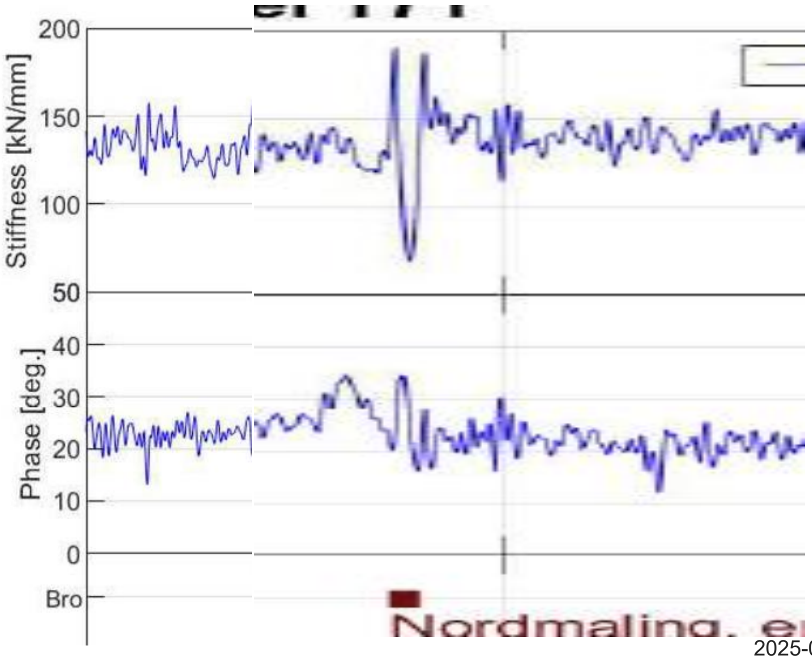
Only a small part of this has had its track substructure changed.

The picture shows Stor-Masse's navy gang when Vännäs-Umeå was built in the years 1895-96. From "the Railway 150 years"

Background - Stiffness measurements on tracks built in recent years

- The Bothnia Line is 185 km long has 140 bridges and 25 km of tunnel and was inaugurated in 2010
- The stiffness variation at the bridge below is large
- => On new tracks, there are too often problems with track stiffness around fixed objects such as bridges and tunnels.





Components and Ballast (1)

UIC have provided two excellent IRS documents namely

IRS70713-1 and 70719-1 – this means that I will not spend time to go into details

But there is one thing you have to have

in mind

The deformation of an USP and an UBM consist of two parts namely one elastic that recovers and a temporary plastic

Picture from Getzner

Components and Ballast (2)

Picture from Getzner

Ballast is the weak link in a ballast track when it comes to elasticity!

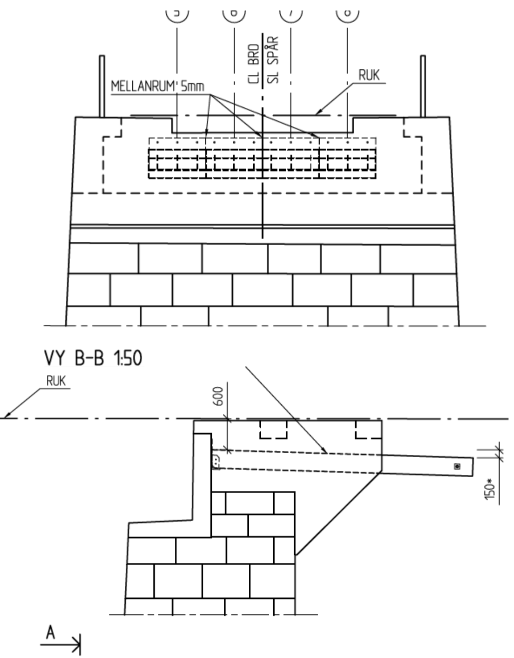
A good report on how ballast breaks down is ERRI D 182 “Unified assessment criteria for ballast quality and methods for assessing the ballast condition in the track”

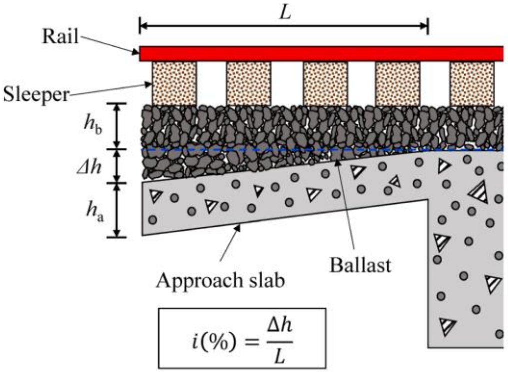
Components and Ballast (3)

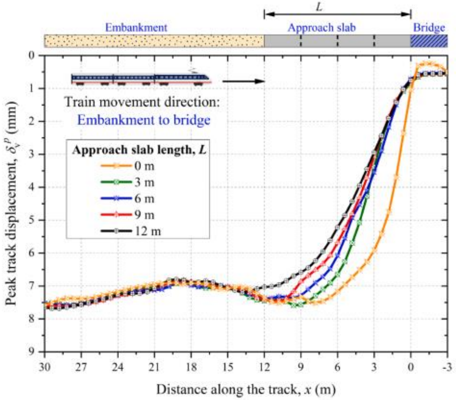
The picture shows a test of whether USPs are an effective technical solution!

Did it work????

Approach Slabs







From an approach slab on a bridge in Vuonjokk on Malmbanan. It is done on an existing bridge.

Approach slabs or Transition Zone slabs will be examined since they have an important impact on track stiffness variations around bridges.

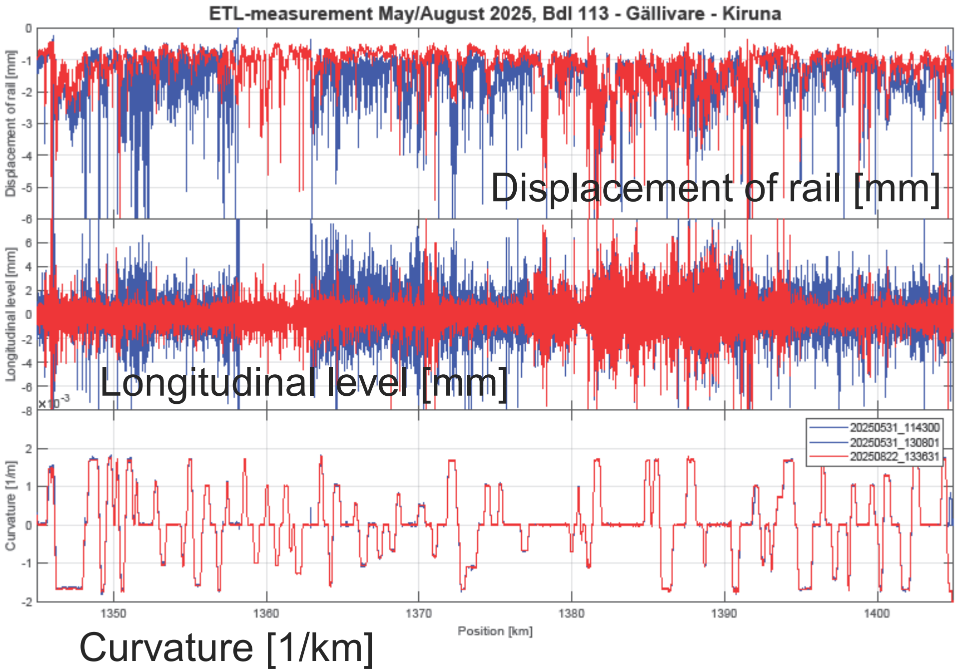
The report “Dynamic behaviour of integral abutment bridge transition under moving train loads”. [Akshay Sakhare et.al] shows another construction. The simulations shows the influence of the length of the approach slab.

Stiffness Measurements (1) – Situation today

- We have two measurement vehicles in Sweden. The latest is IMV200, see right. It has LATRONIX measuring equipment. shown on bottom left.
- At bottom right is the older RSMV (Rolling Stiffness Measurement Vehicle). It has not been used lately.
- This year we have carried out three measurements campaigns. One in southern Sweden for our geotechnicians and two on the Malmbanan (the Oreline in the north). I will show results from these two.

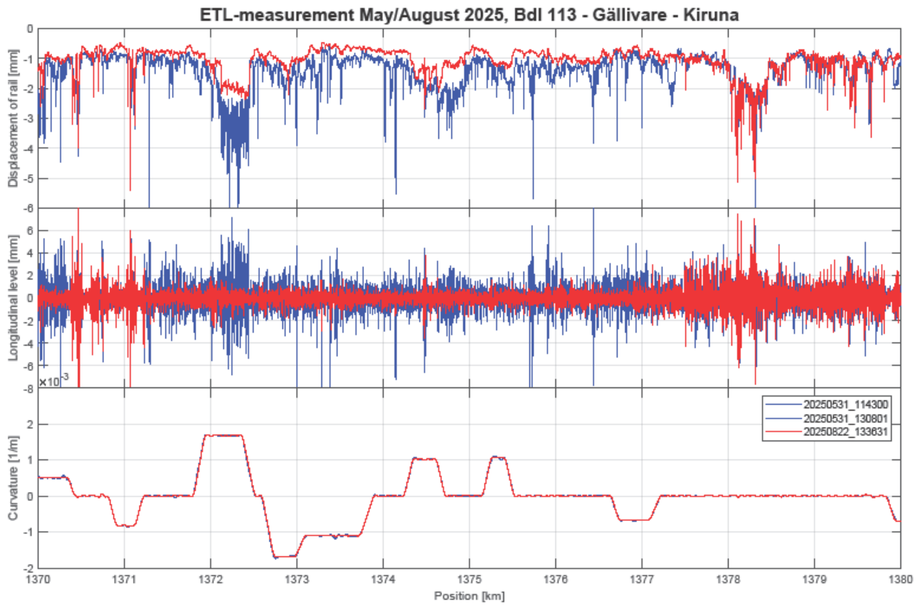
Stiffness Measurements (2)

- **Figure_1345_1405**
- The 60 km part between Gällivare – Kiruna that is subjected to track renewal during 2025. Two displacement/stiffness measurements are shown. One in May (blue) and one in August (red).
- A large portion of the track renewal has been carried out between the two measurements, which is clearly seen as a change in displacement (upper figure) and longitudinal level (middle figure).



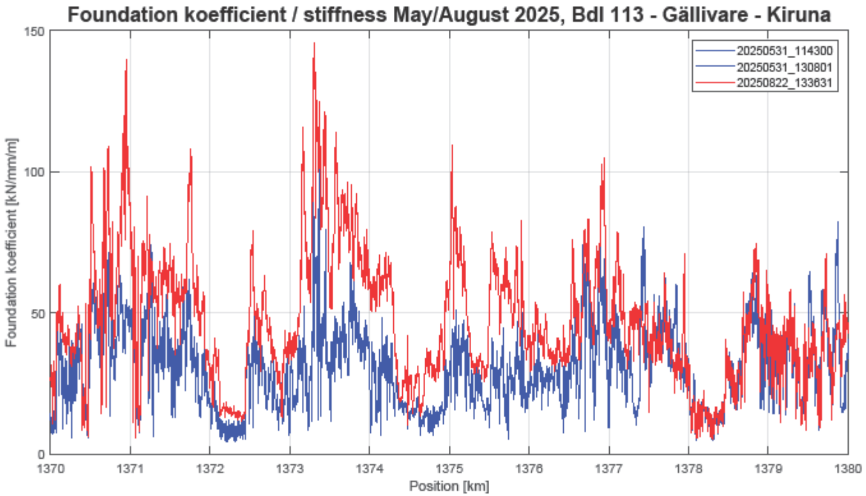
Stiffness Measurements (3)

- **Figure_1370_1380**
- A zoom-in of 10 km, where we see the track renewal, which was completed between km 1370 – 1377+500. The following section is due for renewal in September.
- After track renewal, the displacement are smaller. Rail is upgraded (50 to 60 kg), stiffer pads are installed and ballast is cleaned, so this was expected. (Sleepers were also changed, but of concrete also before change).
- In some areas, e.g. 1372+100-300m, the renewal has also significantly reduced the stiffness variability, which was a large part of the longitudinal level.
- After km 1377+500 it is also clear that the renewal is not yet done. The measurements from May and August are very much the same.



Stiffness Measurements (4)

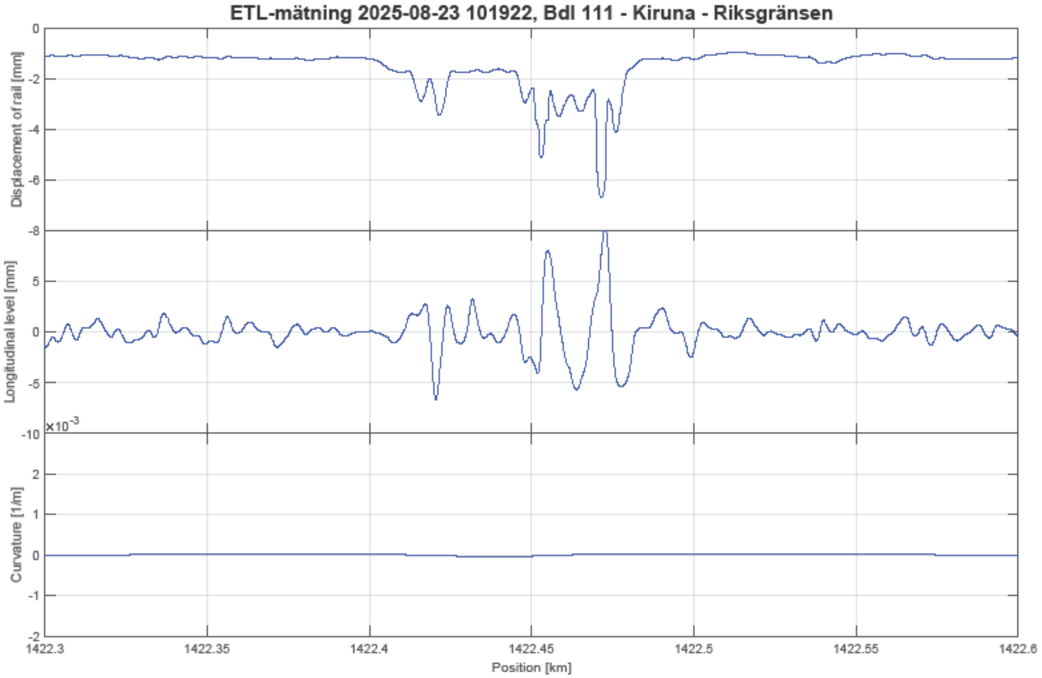
- **Figure_Stiffness_1370_1380**
- Calculation of displacement is based on four track geometry systems placed at different distances from the loaded bogie. An Euler beam on Winkler foundation is fitted to the measurements, from which the displacement is calculated.
- In the model a foundation coefficient is estimated (kN/mm/m - related to stiffness kN/mm). This foundation coefficient is displayed for the same km 1370 – 1380. We can clearly see the stiffer behaviour after track renewal.



Found action coefficient [kN/mm/m]

Stiffness Measurements (5)

- **Figure_approach_plate_1422**
- The figure shows measurements at a zoom-in of a steel bridge with approach slabs.
- The bridge supports are the high-points in longitudinal level. There is a larger displacement at the bridge
- . Short-waved deflection variations are not accurately estimated and in this case the results are probably not fully synchronized with longitudinal level.



Stiffness Measurements (6) – The situation internationally

- **Europe;** According to the questionnaire not much is going on. At the same time there are a lot of interesting activities going on according to papers and reports.
- **America;** Another report from the Brazil and US shows how to use stiffness measurements. Conclusions below.
- Current inspection practices focus on assessing the condition of the track components and geometry.
- This study shows the use of a methodology that utilizes an autonomous vertical track deflection measurement system mounted on a loaded rail car (36 tonnes/axle) in a heavy haul railroad located in southeast Brazil.
- The system continuously measured substructure stiffness along the railway line. Over one year, data has been collected from over 8000 km of track.
- A method to classify weak track areas was developed to enable more effective maintenance planning.

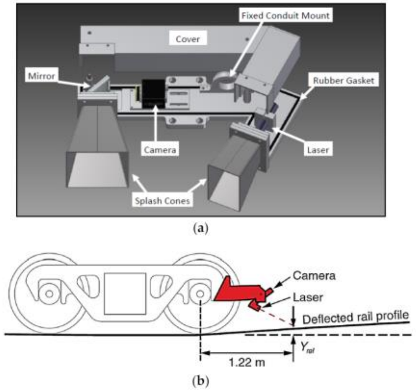
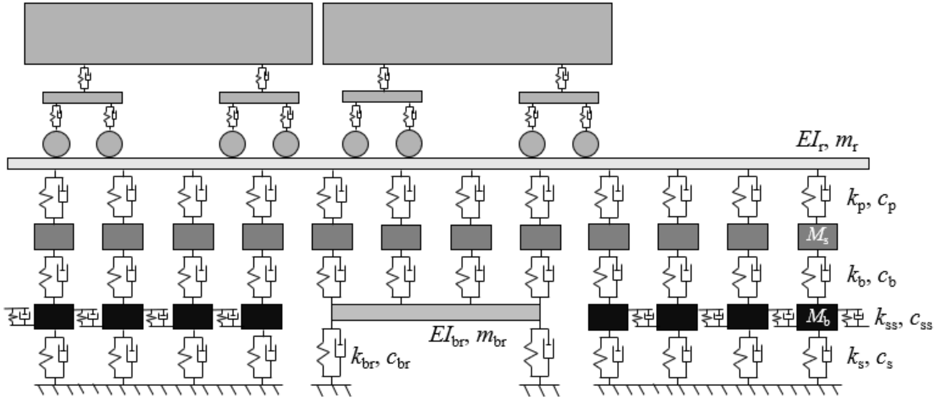


Figure 3. (**a**) MRail system configuration; (**b**) system installed in a bogie frame [9].

Simulations (1) – Indata to DIFF

- The length of the track model is 150 sleeper bays. The bridge supports are positioned from sleeper 69 to sleeper 80.
- The train model is two ore-wagons running in 60 km/h. They enter from the left end of the track model.
- The bridge is modelled as an Euler-Bernoulli beam (developed by KTH).



Simulations (1) – Indata to DIFF and load combinations

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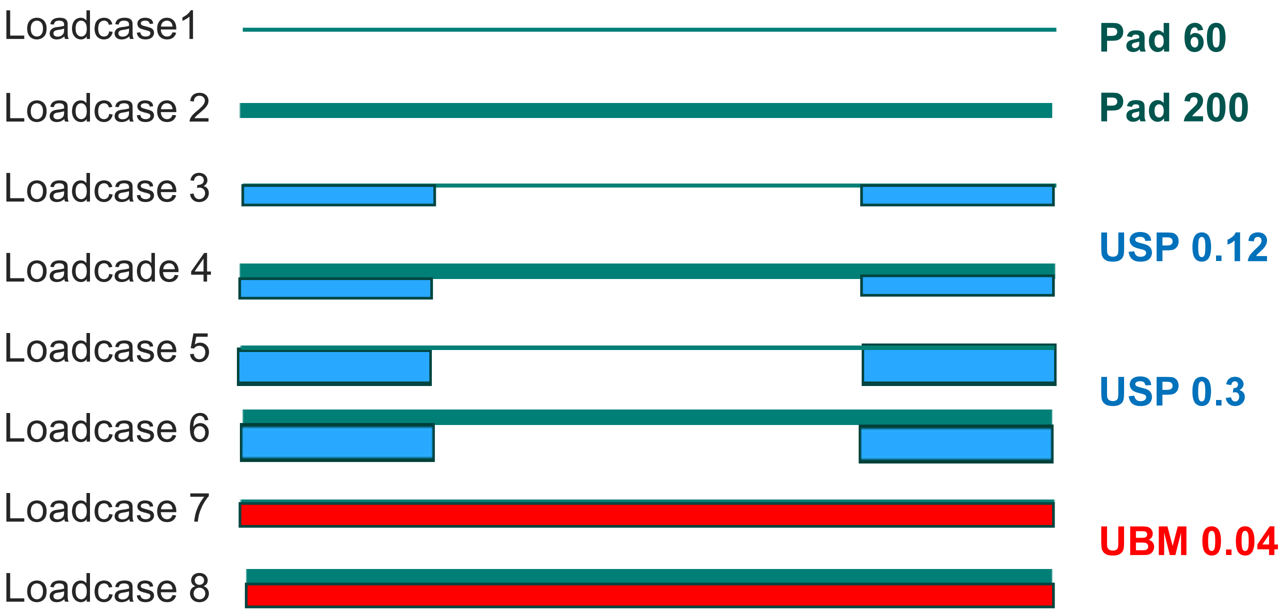
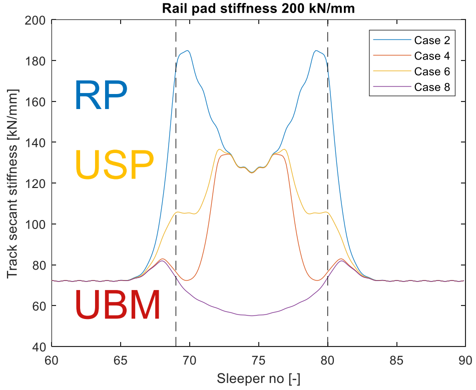
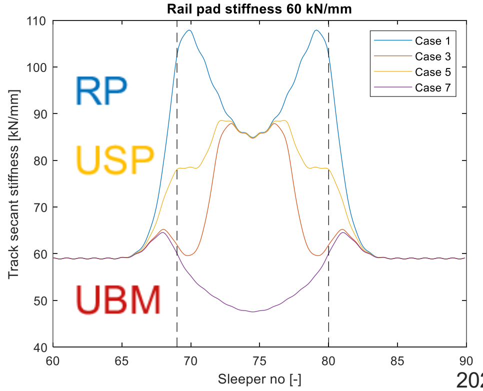
- In this feasibility study it was necessary to limit the number of parameters but at the same time show how the different track components affect the stiffness. Therefore, eight different load cases were chosen.



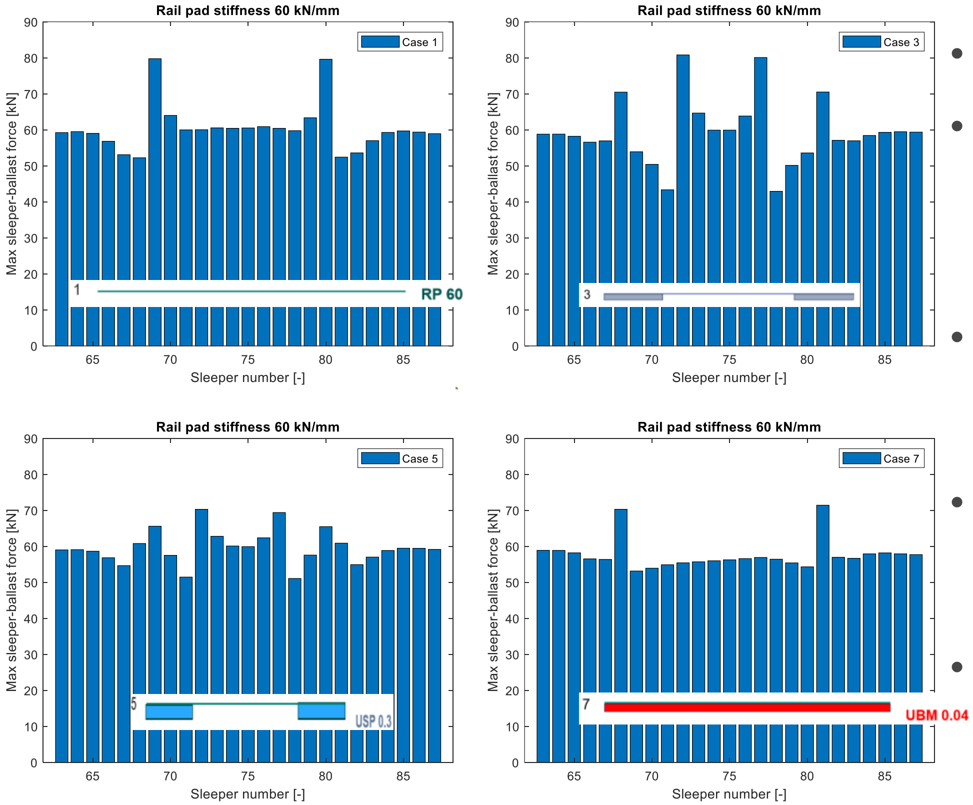
Simulations (2) Track stiffness at rail level (note different scales, vertical dashed lines indicate bridge supports)

- Track stiffness at rail level is the ratio between the vertical static load applied on the rail and the corresponding calculated rail displacement (considering all elements of the track model).
- The implementation of USP or UBM leads to a significant reduction of the stiffness gradient at the entry and exit of the bridge.
- A higher rail pad stiffness leads to a larger stiffness gradient.
- Cases 5 and 6 lead to a smoother change in track stiffness than Cases 3 and 4 (with softer USPs).



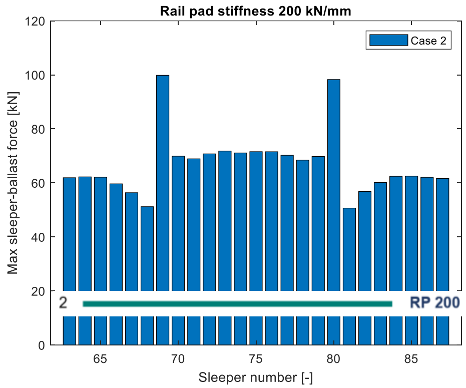


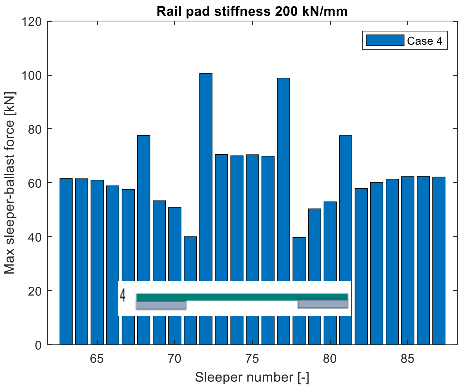
Simulations (3) Maximum sleeper-ballast force per sleeper

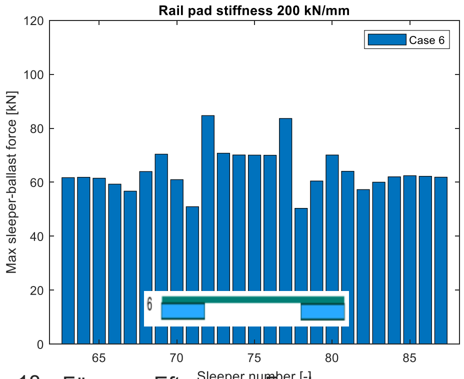


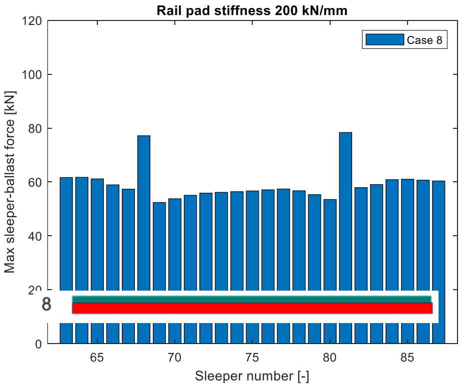
- Loadcase 1,3,5 and 7 /the soft pad)
- Based on the calculated time history of sleeper – ballast force for each sleeper in the track – bridge model, the maximum contact force is extracted and compared.
- For the reference case (Case 1), the maximum sleeper – ballast forces are generated at the bridge supports.
- Cases 5 and 7 lead to a better distribution (and lower) sleeper – ballast forces than Cases 1 and 3.
- The four cases will be compared in the same plot on the next slide (also for rail pad stiffness 200 kN/mm).

Simulations (4) Maximum sleeper-ballast force per sleeper









- Loadcase 2,4,6 and 8 (the stiffer pad)
- Based on the calculated time history of the sleeper-ballast force for each sleeper in the track-bridge model, the maximum contact force is extracted and compared.
- For the reference cases (Cases 1 and 2), the maximum sleeper-ballast forces are generated at the bridge supports.
- Cases 6 and 8 lead to a better distribution (and lower) sleeper-ballast forces than Cases 2 and 4.
- Note different scale on the vertical axis in these plots compared to the similar plots for Cases 1, 3, 5 and 7.

Proposal 1 – ”Track Friendly Bridges”

- As a first step, a project to make bridges with ballast more track friendly. The reason to start with bridges is that the track substructure of bridges is better defined since it only consists of ballast and track components.
- Simulations show that transition zones need to be investigated more carefully. With better knowledge, better input data will give more realistic results. One way, is to study stiffness measurement data in detail for transition zones. Also check trends for variations over time with exposure to traffic loads.
- Approach slabs can reduce rapid stiffness variations. A summary of “best praxis” in different railway administrations could be a first step.
- Input data is needed for ballast. Understand that ballast behaves like a spring whose elasticity deteriorates over time when exposed to traffic. [ERRI 182 Rp 3].

Proposal 2 – A General Proposal

- A proposal is made for a more general stiffness measurement project. It is more complicated and requires better knowledge of the track substructure.
- Often, the track substructure is not sufficiently known, especially on older tracks.
- A first step is to gain knowledge of the track substructure. This was done on Malmbanan during the upgrade to STAX 30 tons.
- It also requires knowledge of how the degradation occurs over periods of time.

Conclusions (1)

- **Measuring track stiffness may reduce maintenance costs** and traffic disturbance. Detect stiffness changes earlier and know how to act.
- Today, **mostly used by geotechnical engineers**. Wider applications in the future.
- Several attempts made but measuring technology was not sufficient.
- Background was presented for a track with **old** subgrade of local material. (Malmbanan). Subgrade varied. A **new** track (Botniabanan) from 2009 was also presented. Both have **clear problems with rapid stiffness variations.** For Botniabanan around bridges and tunnels.

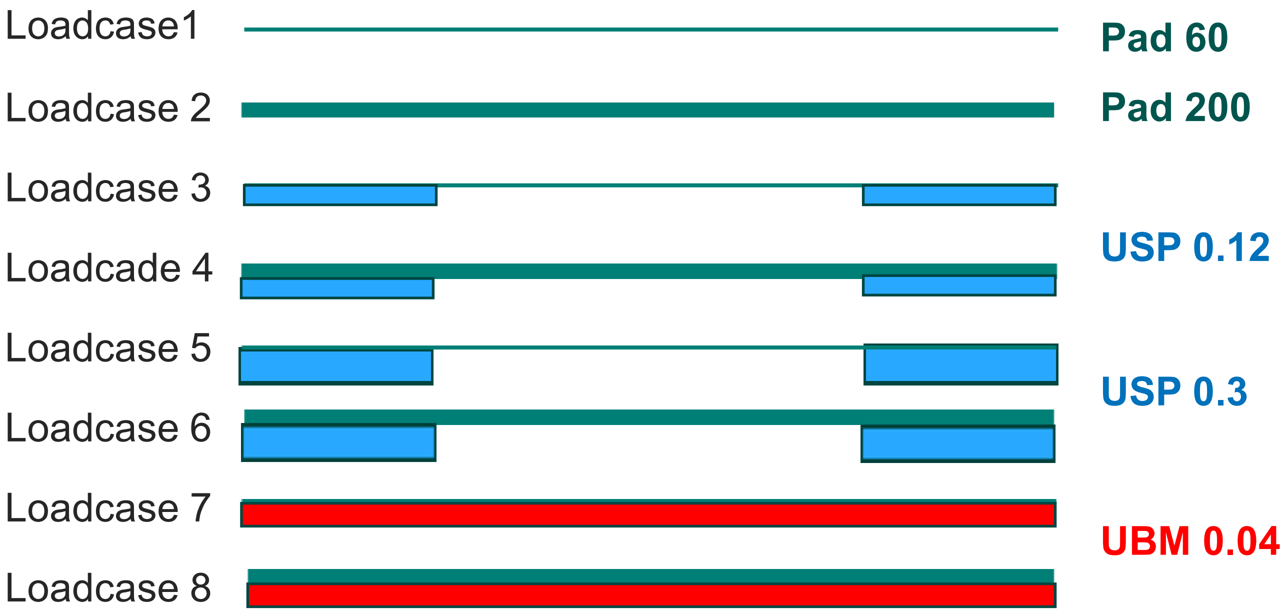
Conclusions (2)

- **Approach slabs** are used today. They can be improved by elastic/plastic track components and simulations.
- The **simulations** also show the importance of the transition zone. The assumptions made in the simulations need to be improved.
- The simulations with **UBM** show that they give a **good effect** even if the transition zone is not optimal.

Proposal for a next step

- Find interseting railway competence
- Start up a
- Arrange a workshop
- Start up a working group
- If this is done I am willing to support with what i have done so far

Thank you for your kind attention!


Loadcase1
Loadcase 2
Loadcase 3
Loadcade 4
Loadcase 5
Loadcase 6
Loadcase 7
Loadcase 8
Pad 60
Pad 200
USP 0.12
USP 0.3
UBM 0.04