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Synthetic fibre reinforcement in concrete structures – applications and design

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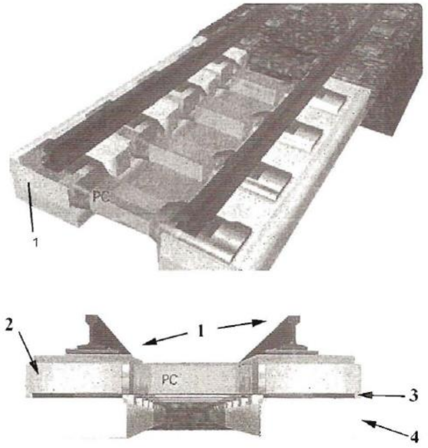
Synthetic macro fibre reinforced concrete structures

- In the past decade macro synthetic fibre reinforcement has become widely used for concrete structures
- Casting time and manual work will decrease, while the concrete's ductility will increase
- Durability will be higher with using synthetic fibres
- Corrosion resistance is the greatest benefit of macro synthetic fibre
- Carbon footprint will be lower compared to steel mesh or steel fibre reinforcement
- Three most common applications:
  - Tramlines (cast in place and precast)
  - Tunnels (shotcrete, cast in place and precast (TBM))
  - Industrial floors

Synthetic macro fibre reinforced concrete tramlines

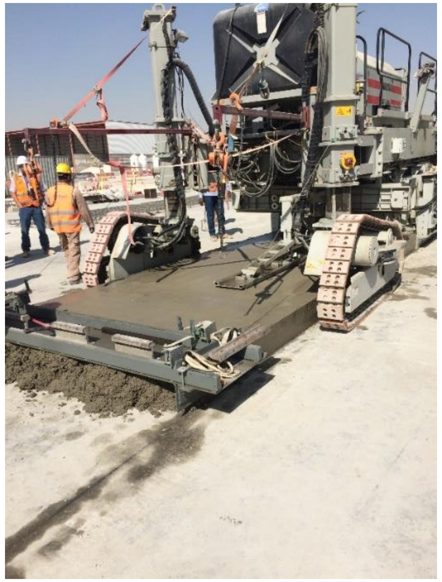
- The first macro synthetic fibre reinforced track slab was constructed in Japan in 2002
- The goal of using macro synthetic fibre was, beside from the reduction of the vibration and noise, to increase the speed of the construction process
- The reinforcement was a hybrid of traditional steel bar reinforcement together with macro synthetic



tramline

Cast in place tramlines

- Two main construction procedures:
  - Pouring in place : installing the formwork the slab is filled with macro synthetic fibre reinforced concrete, the joints are installed after each section of the track slab is poured
  - Track slab extruded machine: the machine continuously pours the macro synthetic fibre reinforced concrete between the moving form work, the joints are made by saw cutting the slab



tramline

Cast in place tramlines – Szeged tramline

- First only macro synthetic fibre (BarChip48) reinforced concrete tramline
- Because of so called „loops” it was necessary to have concrete track slabs that contained no steel reinforcement
- Due to the good experience synthetic fibers were used for all the other sections as well
- During the design process the dynamic loads of trams and buses were taken into account
- Load-bearing capacity, serviceability and fatigue limits were checked

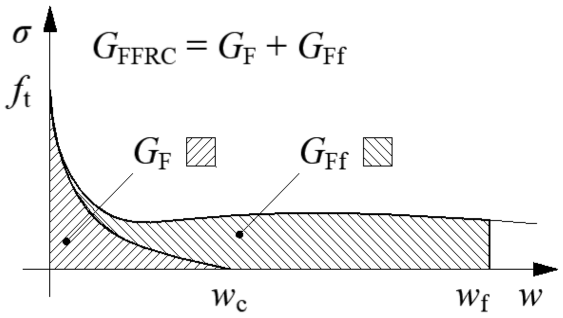
- After the success of Szeged several other tram tracks were constructed using very similar solutions and using macro synthetic fibres (St. Petersburg, Russia, Tallinn, Estonia, Budapest Hungary)

tramline

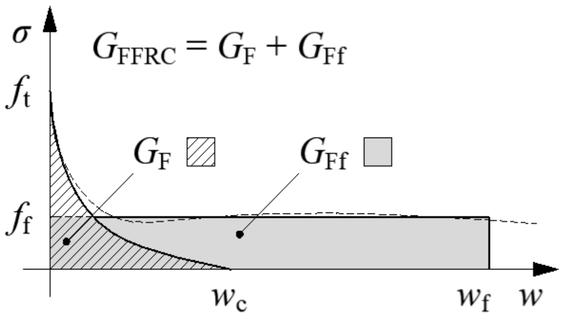
Cast in place tramlines – Szeged tramline

Cast in place tramlines – Szeged tramline

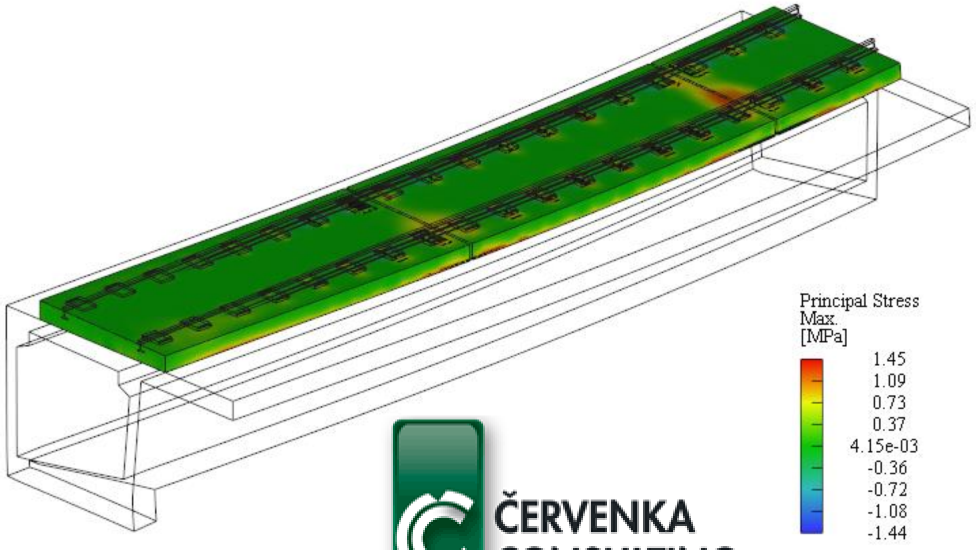
- Concrete specific finite element software should be use for the design and optimization - ATENA and the DiANA
- Different behavior for tension and compression
- Post-cracking behavior – crack propagation, crack width calculation
- Effect of synthetic fibers were taken into account with Modified Fracture Energy Model



experimental diagram



numerical diagram



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tramline

Precast concrete tramlines

- Elements are made in precast concrete factories and transported to site
- Beside final load cases other effects: early age demoulding, rotation, lifting, stacking, transporting and installation on site
- Elements are made from concrete with higher strengths i.e. from C40/50
- Precast elements have a higher dosage of macro synthetic fibre to the track slabs that are cast in place

tramline

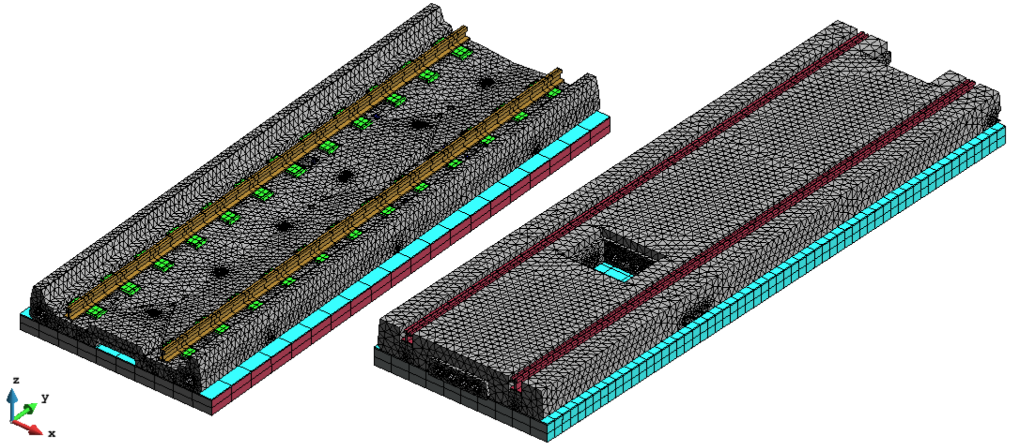
3 The PCAT system

- PreCast Advanced Track's (PCAT) unique 100 per cent macro synthetic fibre reinforced precast concrete slab
- The design is based on a channel beam upper profile which provides a high stiffness which maximising the slab's strength
- The slabs connect to each other with a dry male female joint for initial alignment and then with curved bolt connections

tramline

- All the details were modelled including the connection ducts, the injection holes, the rail sleepers and the rails with their exact geometry
- One and a one half slab was modelled to be able to investigate the behaviour of the joints
- Interface elements were used: one to model the friction between the concrete slab and the steel duct, and one to model the transfer of the compression forces between the two slabs

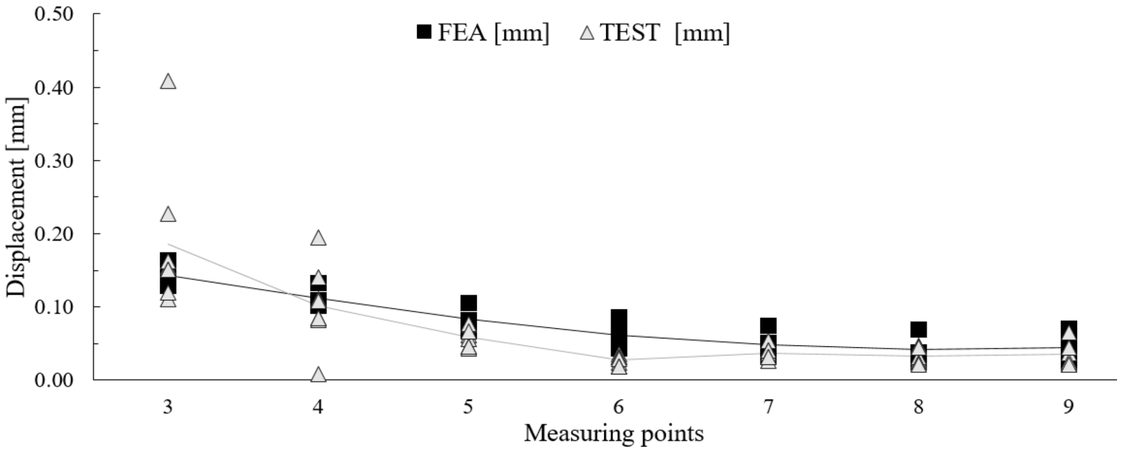
Numerical analysis of the precast track slabs



tramline

Real scale test

- The slab was installed to measure the actual deflection of the slab along the structure using an applied load at various locations
- The loading of the slab was carried out using the Rail Trackform Stiffness Tester (RTST) by AECOM
- 9 geophones were positioned to record the deflection in microns.
- The position of the load was replicated the arrangement used in the FEM
- The model contained the whole test setup including: the concrete pit, the compacted soil, and the two slabs with the previously mentioned detail



tramline

The Shanghai Metro extension

- 1)Preliminaries

  Full scale laboratory test for Shanghai Metro Extension was made in Shanghai, China, Tongji University (prof. Bai).

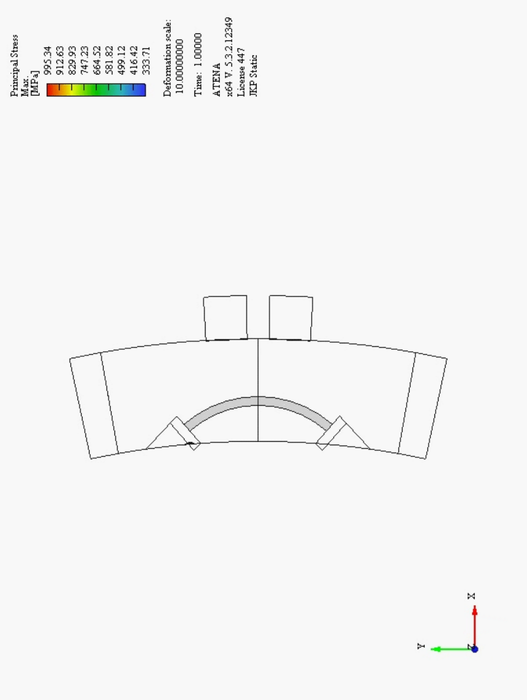
- 2)Verification

  Original traditional reinforced concrete structure was modelled by ATENA and the load-deflection results were compared.

- 3) Location of the weakest point
- At joints.
- 4) Optimizations by fibre

  replace steel bars by synthetic macro fibre (BarChip54)

  strengthening the weakest point



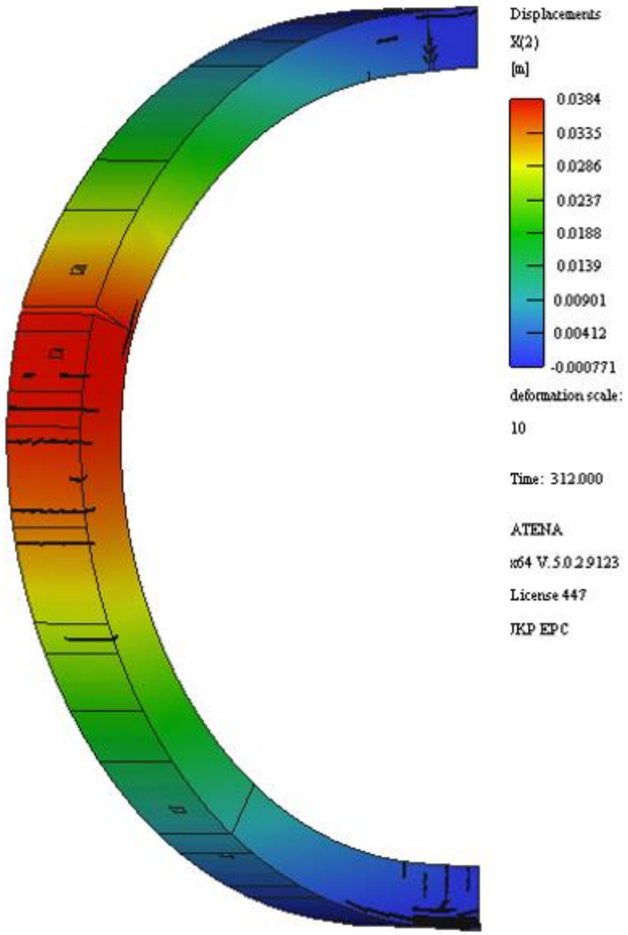
tunnel

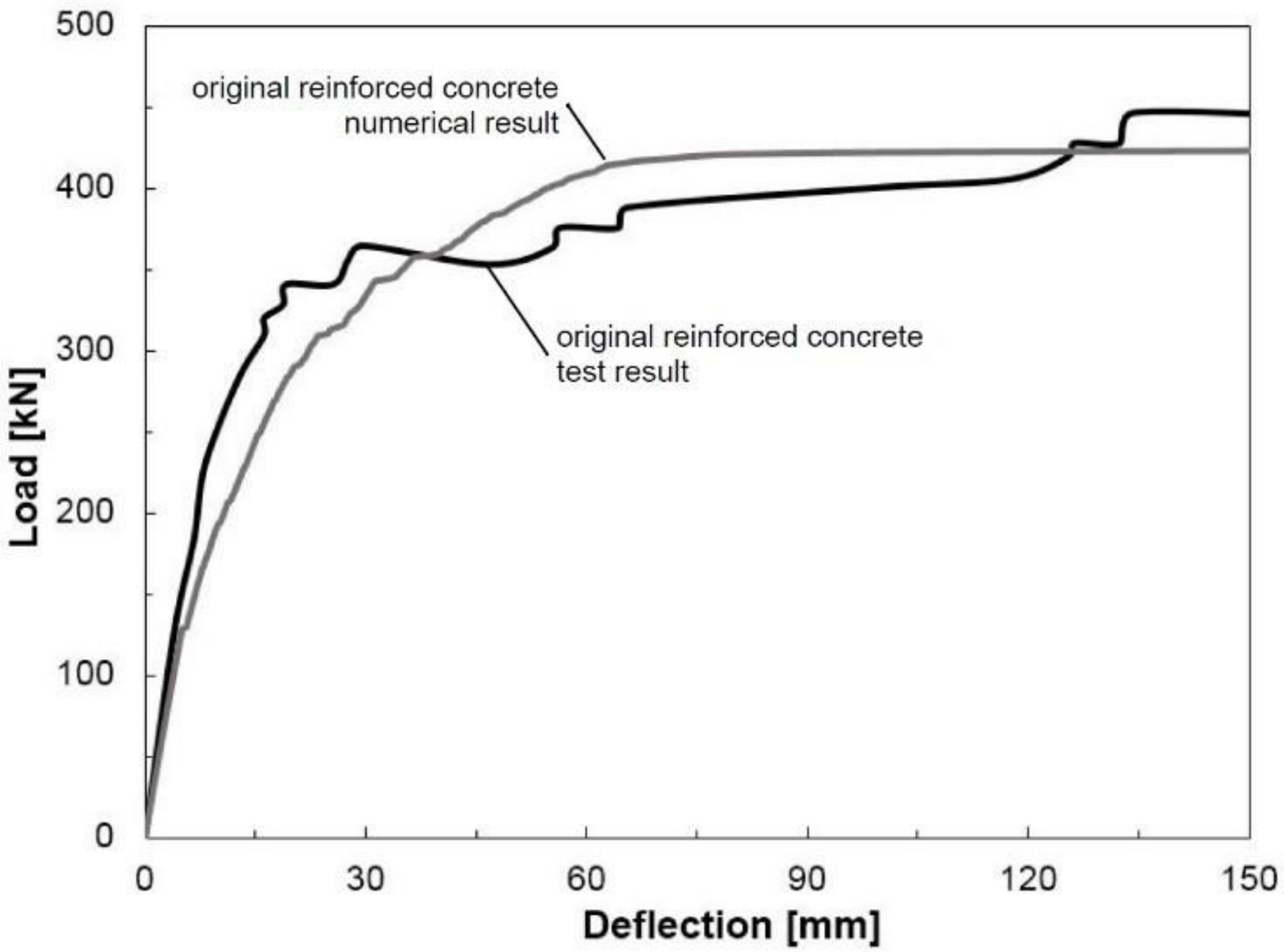
Real scale test in the Tongji University

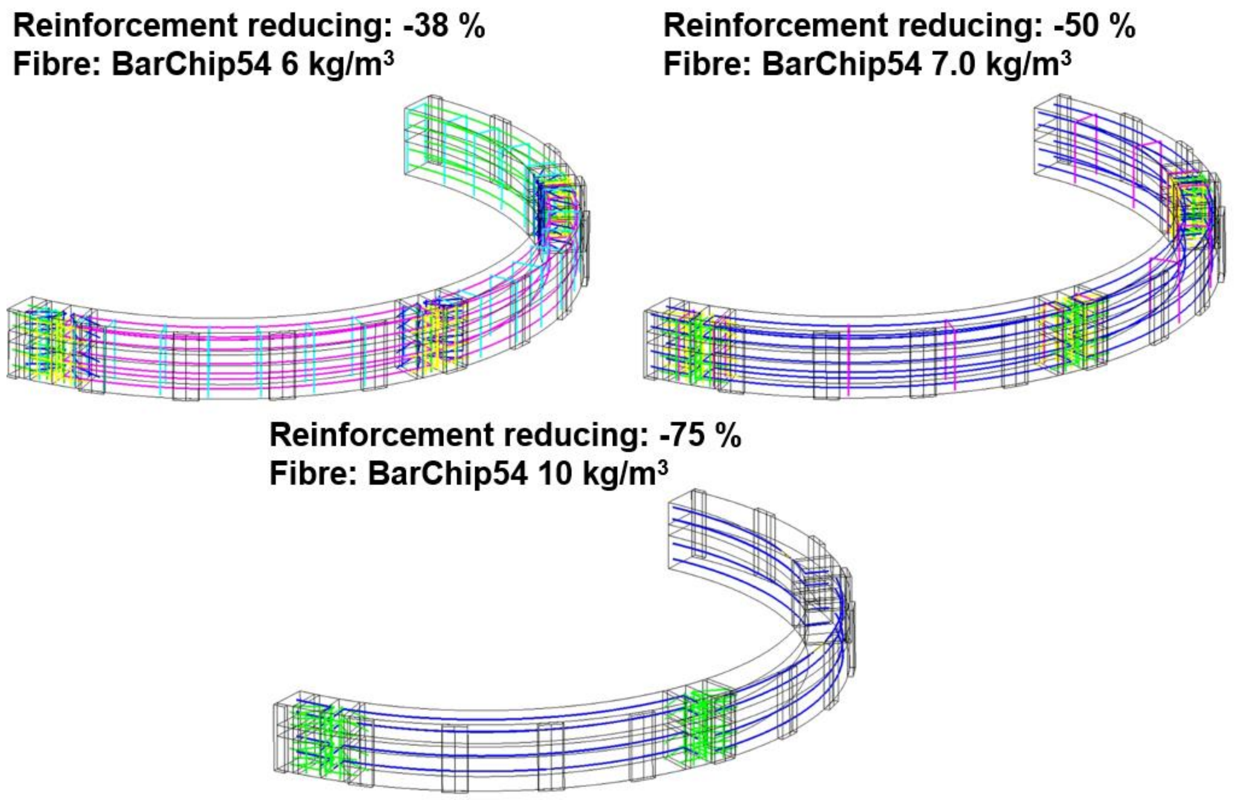
- 1 to 1 model of the full round tunnel was tested at the Tongji Univesity in Shanghai with the original reinforcement cage, and has been tested with different loads while the deflection was measured until total failure.

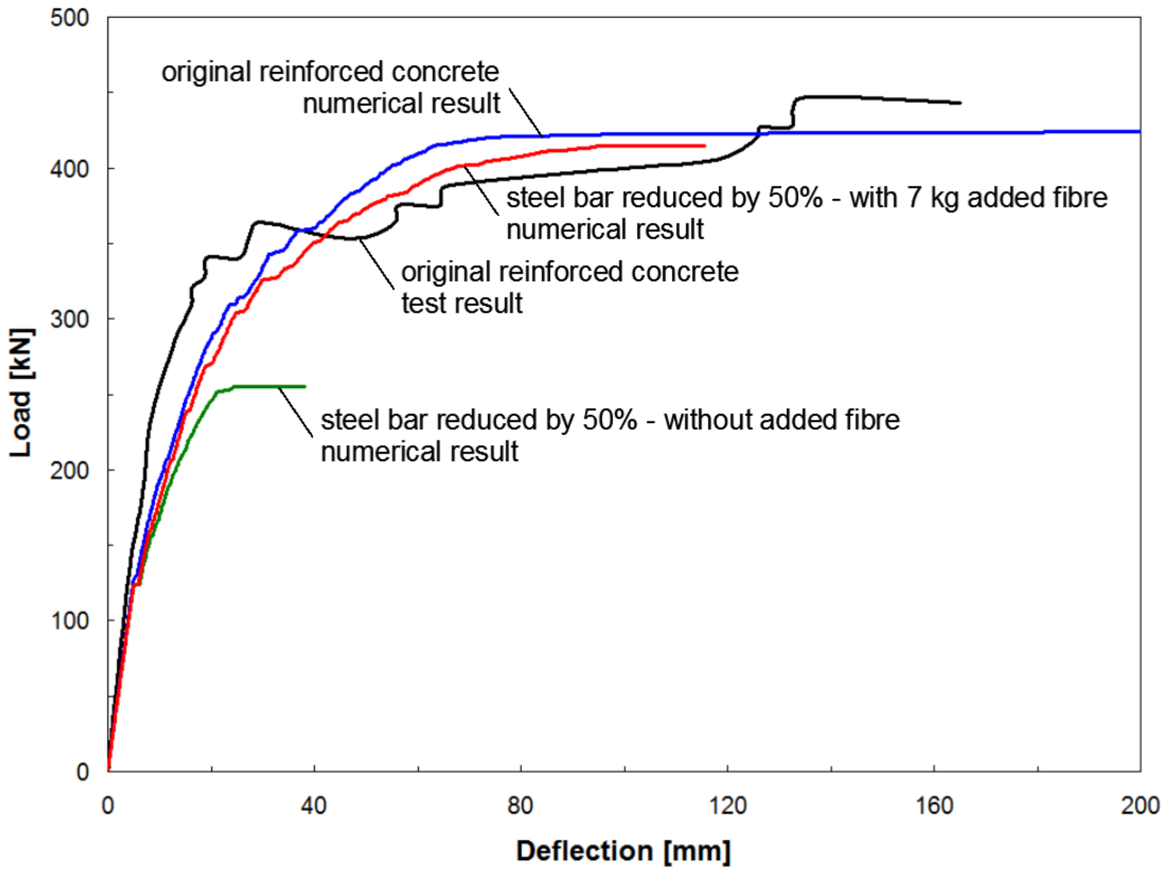
tunnel

- Load-displacement of the traditional reinforced TBM tunnel



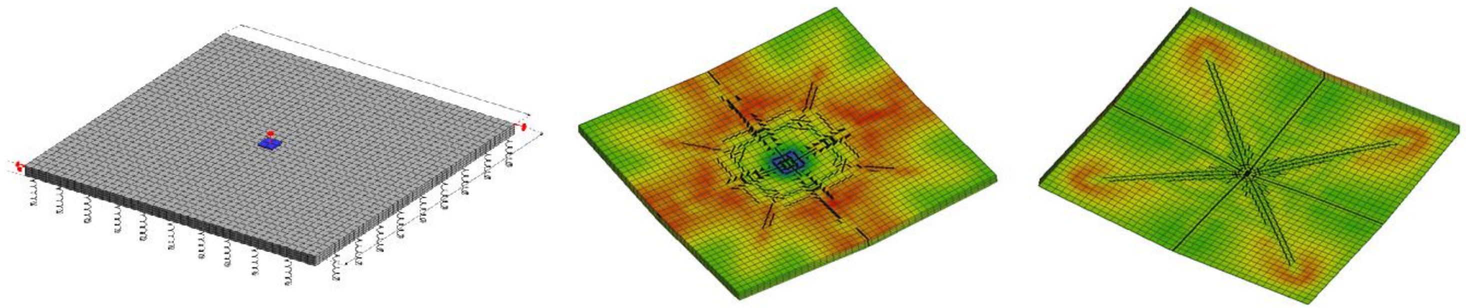



Reinforcement reducing: -38 %
Fibre: BarChip54 6 kg/m3
Reinforcement reducing: -50 %
Fibre: BarChip54 7.0 kg/m3
Reinforcement reducing: -75 %
Fibre: BarChip54 10 kg/m3

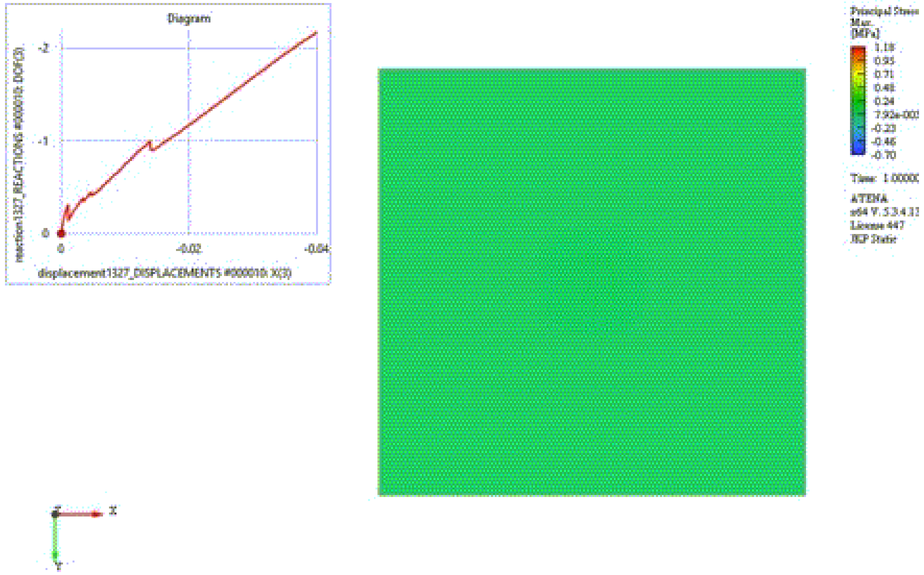

Load [kN]
Deflection [mm]
0
100
200
300
400
500
0
40
80
120
160
200
original reinforced concrete numerical result
steel bar reduced by 50% - with 7 kg added fibre numerical result
original reinforced concrete test result
steel bar reduced by 50% - without added fibre numerical result

tunnel

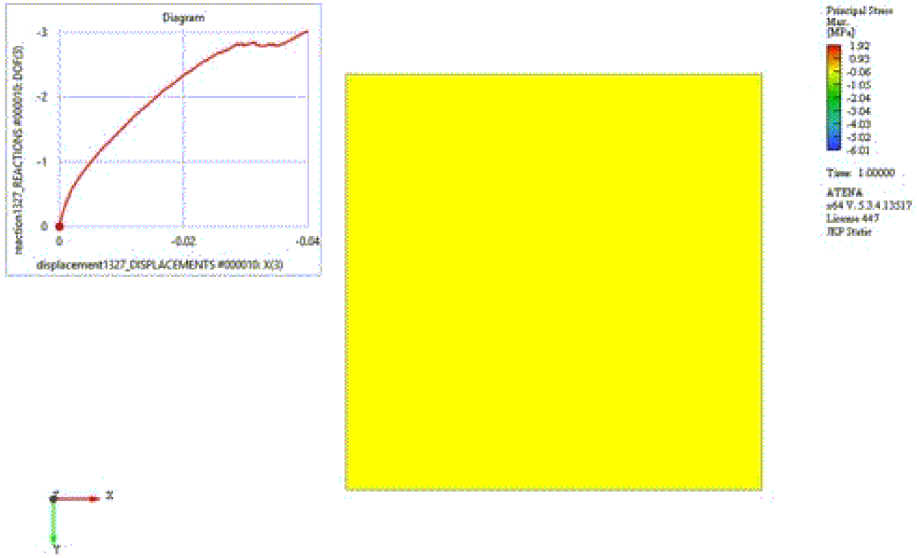
- Only a few design methods available for FRC industrial floors
- UK Concrete Society's Technical Report 34 (TR34)
- With finite element method the FRC industrial floors can be calculated more precisely
- Subgrade can be modelled with non-linear springs or 3D Drucker-Prager material models
- For FRC layer the Modified Fracture Energy Method can be used



Difference in crack propagation of PC and FRC



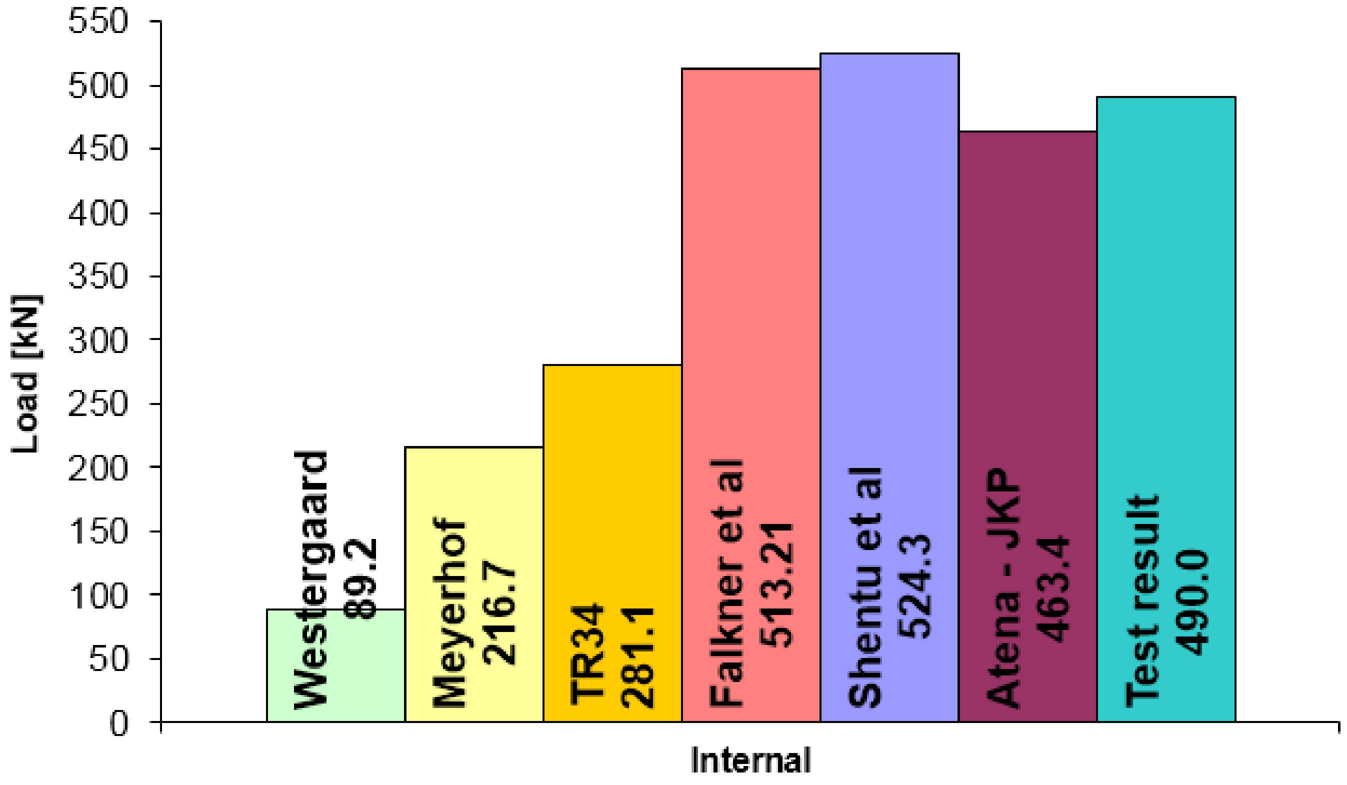
Plain concrete



Fibre reinforced concrete

Industrial floors

Atena Load and other Calculated Loads for FRC Concrete_50Mpa



Industrial floors

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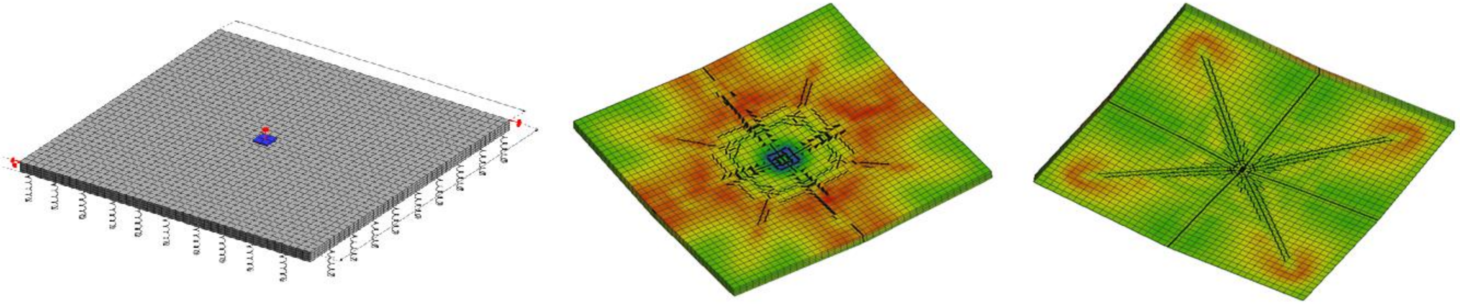

6 Conclusion

- Macro synthetic fibre reinforcement are becoming more and more common in concrete structures
- Some structures are heavily exposed to weather and mechanical loads, and must have sufficient ductility and durability
- Design and optimizing of the structures means the determination of the required thickness of the elements and the macro synthetic fibre dosage for the varying load cases, such as ultimate and serviceability limit state, and fatigue
- For these special tasks advanced finite element software is needed.
- The influence of the fibers could be taken into account by the modification of the fracture energy of the plain concrete.
- These design models have been validated by full scale laboratory tests.
- Huge potential for reducing CO2 emissions, which will be an important task for future engineers

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Thank you for your attention!

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