SSCS 2012
Numerical Modeling
Strategies for Sustainable Concrete Structures

Lattice model as a tool for modeling transport phenomena in cement based composites

Branko Šavija
José Pacheco
Rob B. Polder
Erik Schlangen

TU Delft

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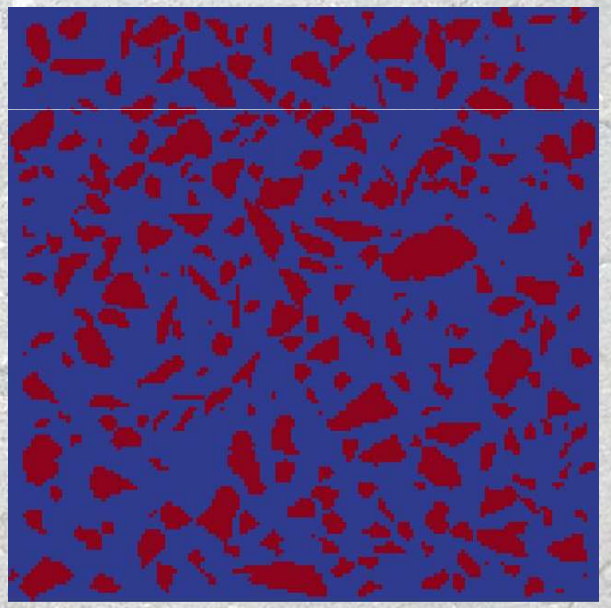
Content:

- Aim of the research
- Lattice models
- Transport model outline
- Verification
- Conclusions

Durability of reinforced concrete:

- Concrete-
  environ
- Increasin **res**
- Main cau aw,
  corrosion
- Water (+c in all
  of them!

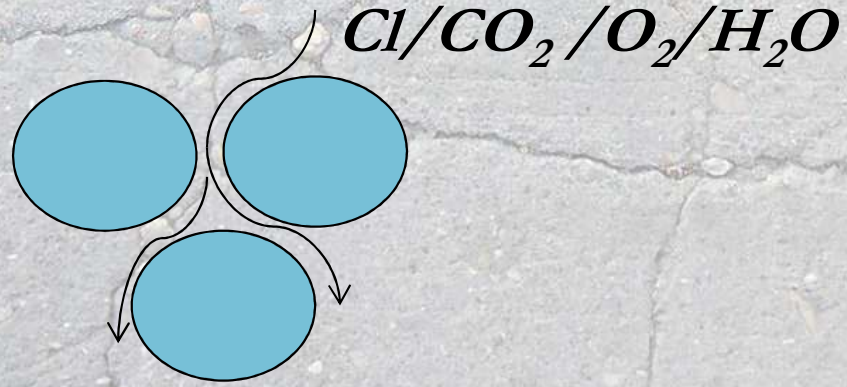
Durability of reinforced concrete:



- Concrete is a **multi-scale** and **heterogeneous** material
- Concrete meso-structure influences it's transport properties

Why study transport properties on the meso scale?

- The importance of aggregate distribution is increasingly emphasized in the literature
- Influence local distribution of species (moisture, CO_2, O_2)
- Influence on the Cl threshold concentration?
- Possible to create more durable concrete mixtures through numerical experimentation?



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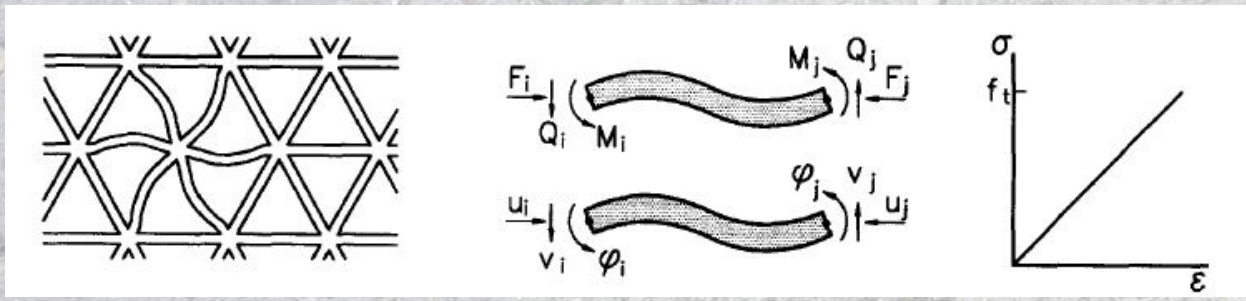
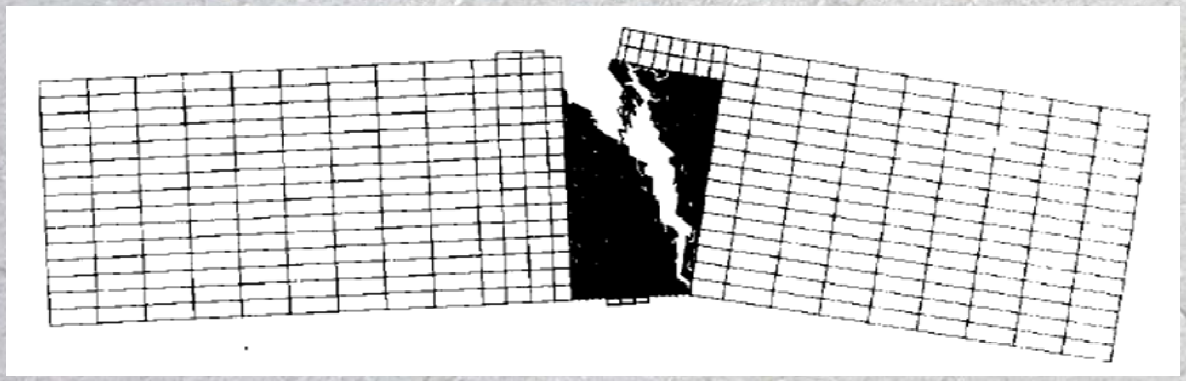
Lattice models in fracture mechanics

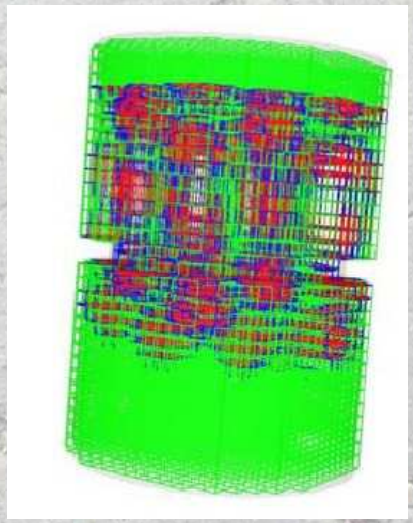
Modelling of concrete fracture- set of beam/truss elements!



(from Schlangen and Garboczi (1997))



(from Schlangen (1993))



(from Schlangen & Qian (2009))

Lattice models for transport phenomena

Concrete discretized as a set of 1D interconnected “pipes”!

Their assembly constitutes a 2D or 3D lattice (pipe) network!

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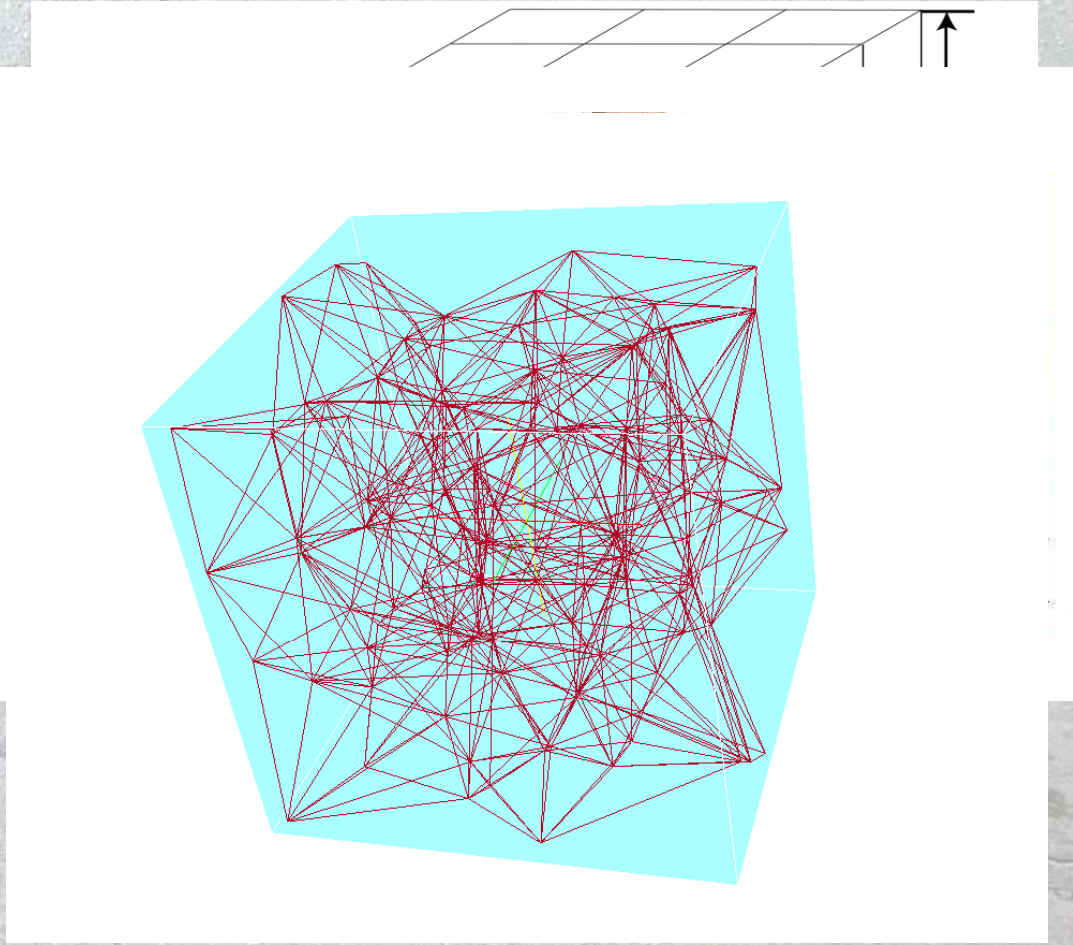
Spatial discretization:

1. Node placement

2. Voronoi tesselation of the domain

3. Nodes in adjacent Voronoi cells connected by elements = Delaunay triangulation



Governing equations:

Governing differential equation (diffusion-type transport)

$$\frac{\partial C}{\partial t} = D\frac{\partial^2 C}{\partial x^2} + Q$$

Concentration (Cl, T, H…)

Conductivity/ Permeability/ Diffusivity

Sink/source (hydration, self-dessication…)

Governing equations:

Discretize using the Galerkin method:

$$M\dot{C} + KC = f$$

Steady-state conditions

$$KC = f$$

Elemental matrices:

$$M = \frac{Al}{6\omega}\begin{bmatrix} 2 & 1 \\ 1 & 2 \end{bmatrix}, K = \frac{DA}{l}\begin{bmatrix} 1 & -1 \\ -1 & 1 \end{bmatrix}$$

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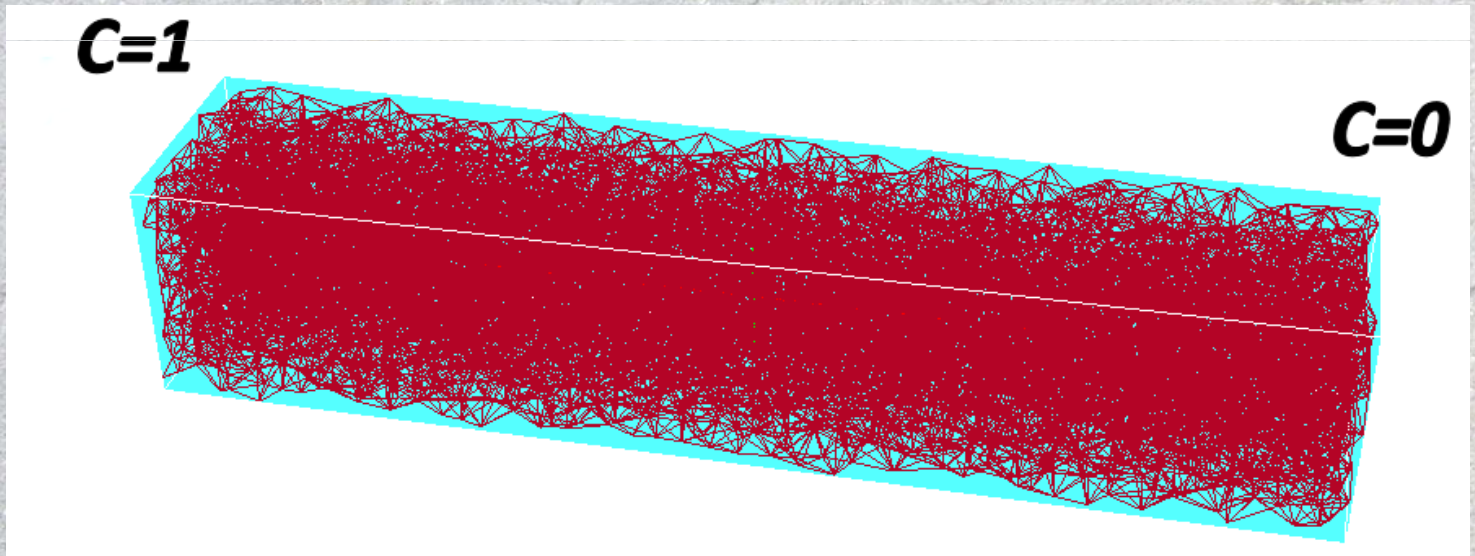
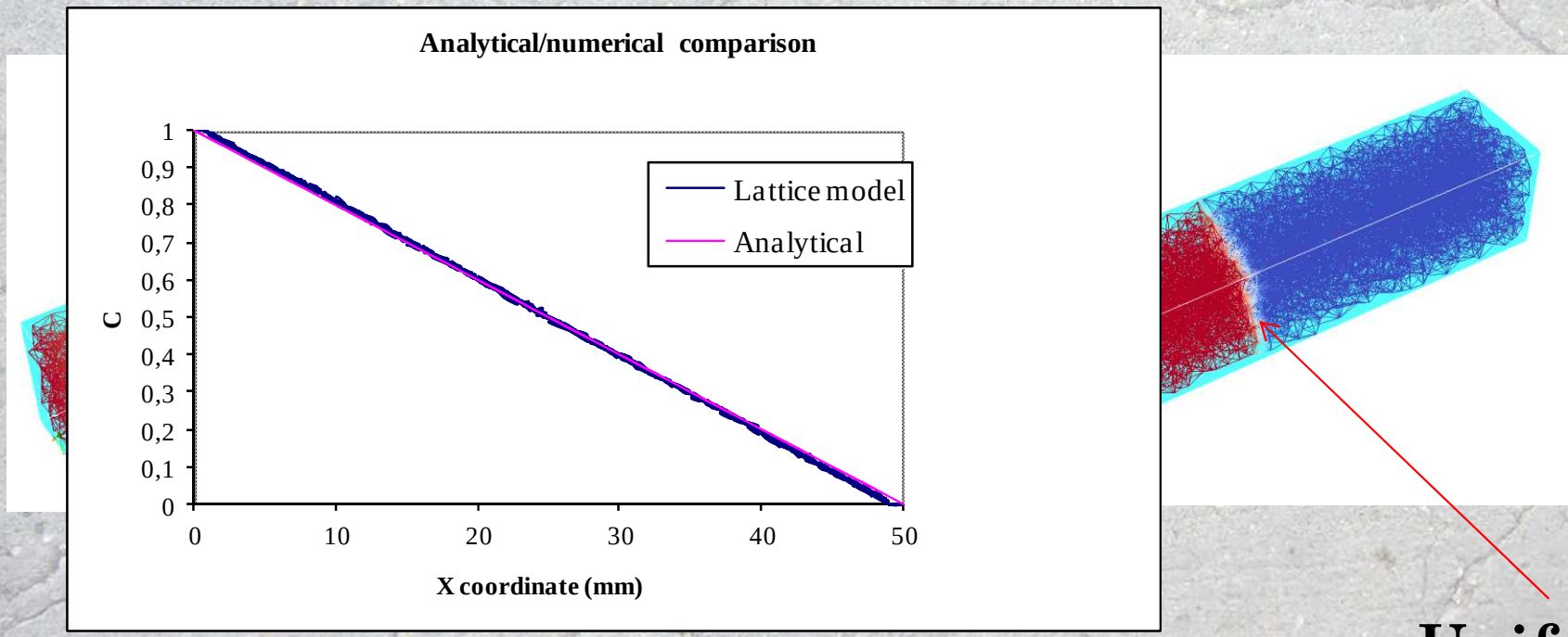
Steady-state diffusion through a homogeneous medium:



Length (mm)	Width (mm)	Thickness (mm)	Total number of nodes	Number of lattice elements
50	10	10	5000	34532

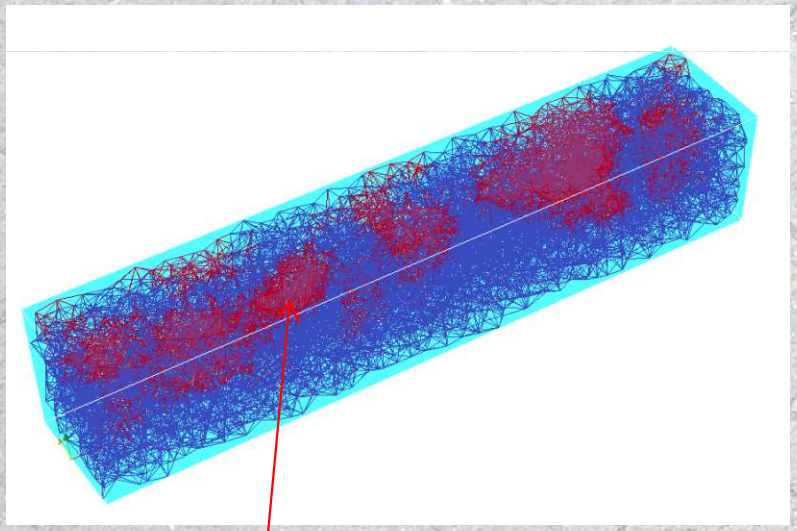
Steady-state diffusion through a homogeneous medium:



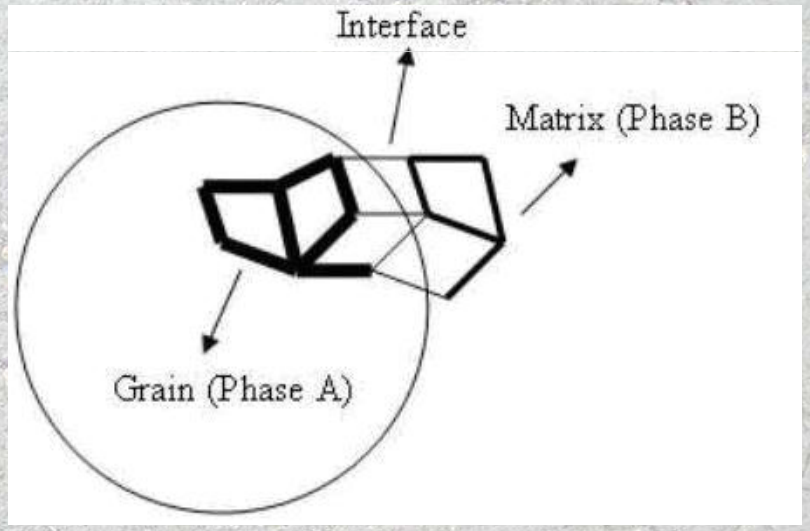
Minimal error (mainly due to boundary conditions)

Uniform penetration front

Steady-state diffusion through a heterogeneous medium:



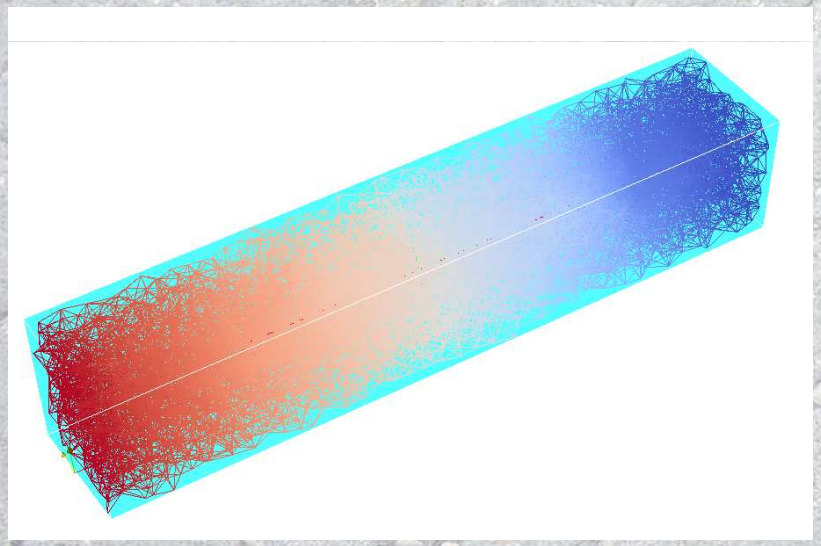
Impermeable aggregate!

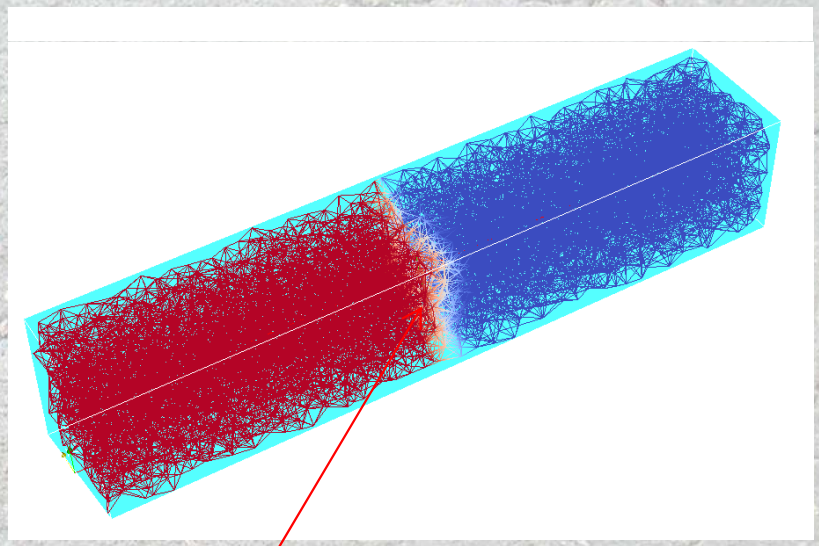


From Qian et al (2010)

As a basis **computer generated concrete meso-structure** was used (*Qian PhD thesis, 2011*)

Steady-state diffusion through a heterogeneous medium:





Preliminary **transient analyses** show a significant role of material heterogeneity!

Non-uniform penetration front (caused by aggregates)

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Conclusions

- When compared to the analytical solution (homogeneous)- **minimal deviations**
- The penetration front is **uniform** for the homogeneous case- **no numerical error** introduced by the lattice randomness
- It is possible to model concrete on the **meso-scale** (i.e. as a heterogeneous material). **Computer generated** or concrete structure obtained by **micro-CT scanning** can be used.
- The inclusion of impermeable aggregates makes the penetration profile **non-uniform**. This behaviour is not observed in homogeneous case, and can be attributed to the material inhomogeneity.

On-going and future work:

- **Transient analysis** of transport processes in heterogeneous concrete (moisture and chloride transport)
- **Coupling** the mechanical and transport lattice model
- **Experimental verification** of obtained results

Thank You very much for Your attention!

See our latest results at: http://microlab-m3c4.blogspot.com/