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Laboratoire Matériaux et Durabilité des Constructions

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Projet National de R&D

Use of original percolation approach in homogenization methods for the prediction of concrete hydro-mechanical behaviour at early age

SSCS 2012
Numerical Modeling
Strategies for Sustainable Concrete Structures

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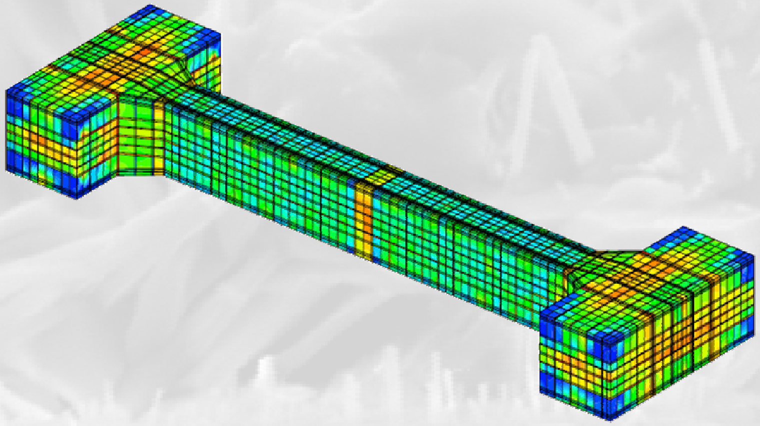
Context

<u>Context</u> : *CEOS.fr* and *Mefisto* French national projects

Task 2 : Concrete structure behaviour under THM loading



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<u>Previous studies and simulations</u>

⇒ Need to improve the prediction of **mechanical properties** at very **early age**

⇒ Need to improve the modelling of **hydro-mechanical** behaviour (properties at **early age** and **hysteresis** phenomenon)

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Use of **multi-scale approach** to predict **hydro-mechanical** properties according to **hydration** prediction

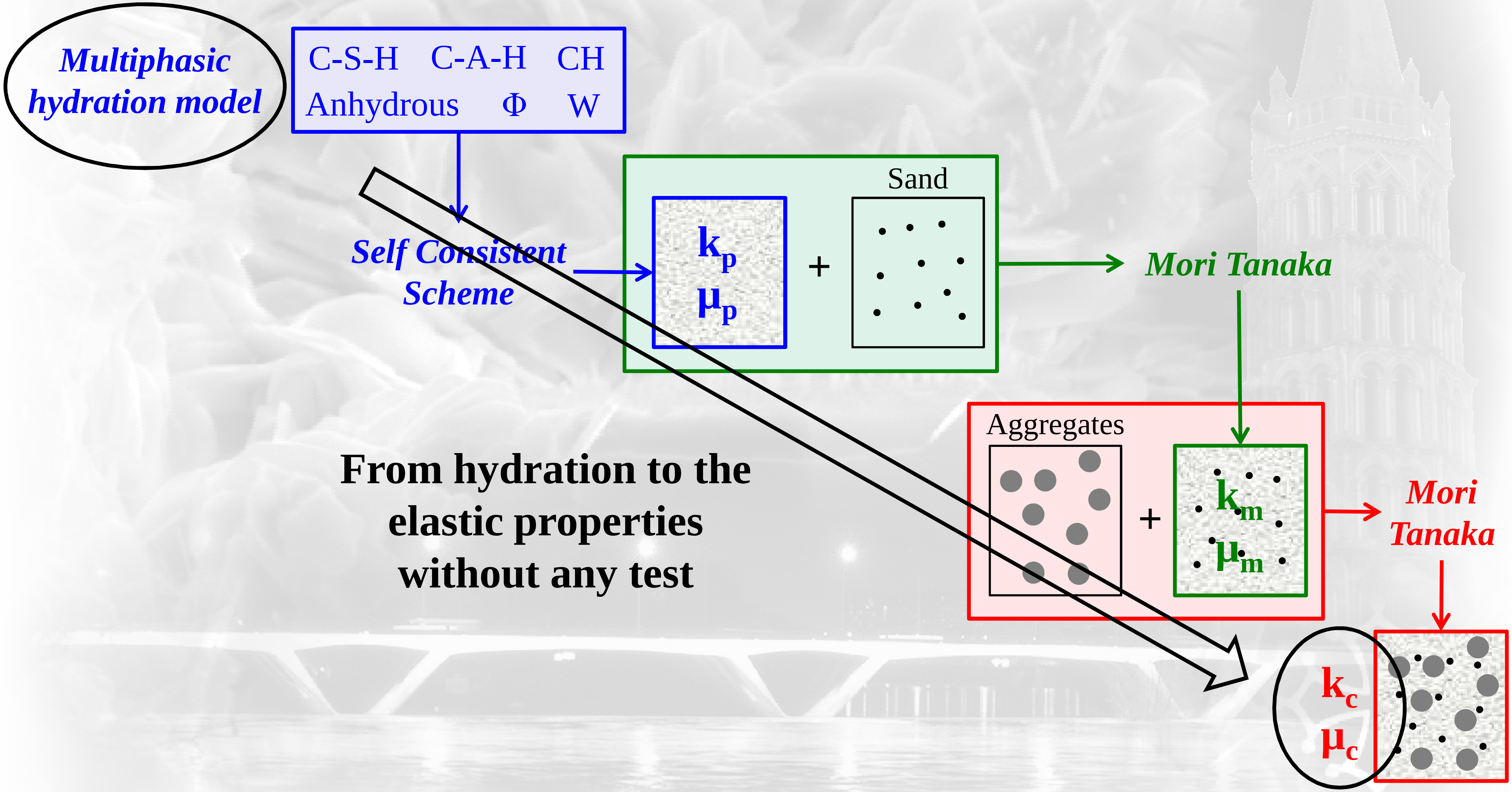
I – Principal of the multi-scale approach

II – Prediction of elastic properties

III – Extension to the hydro-mechanical properties

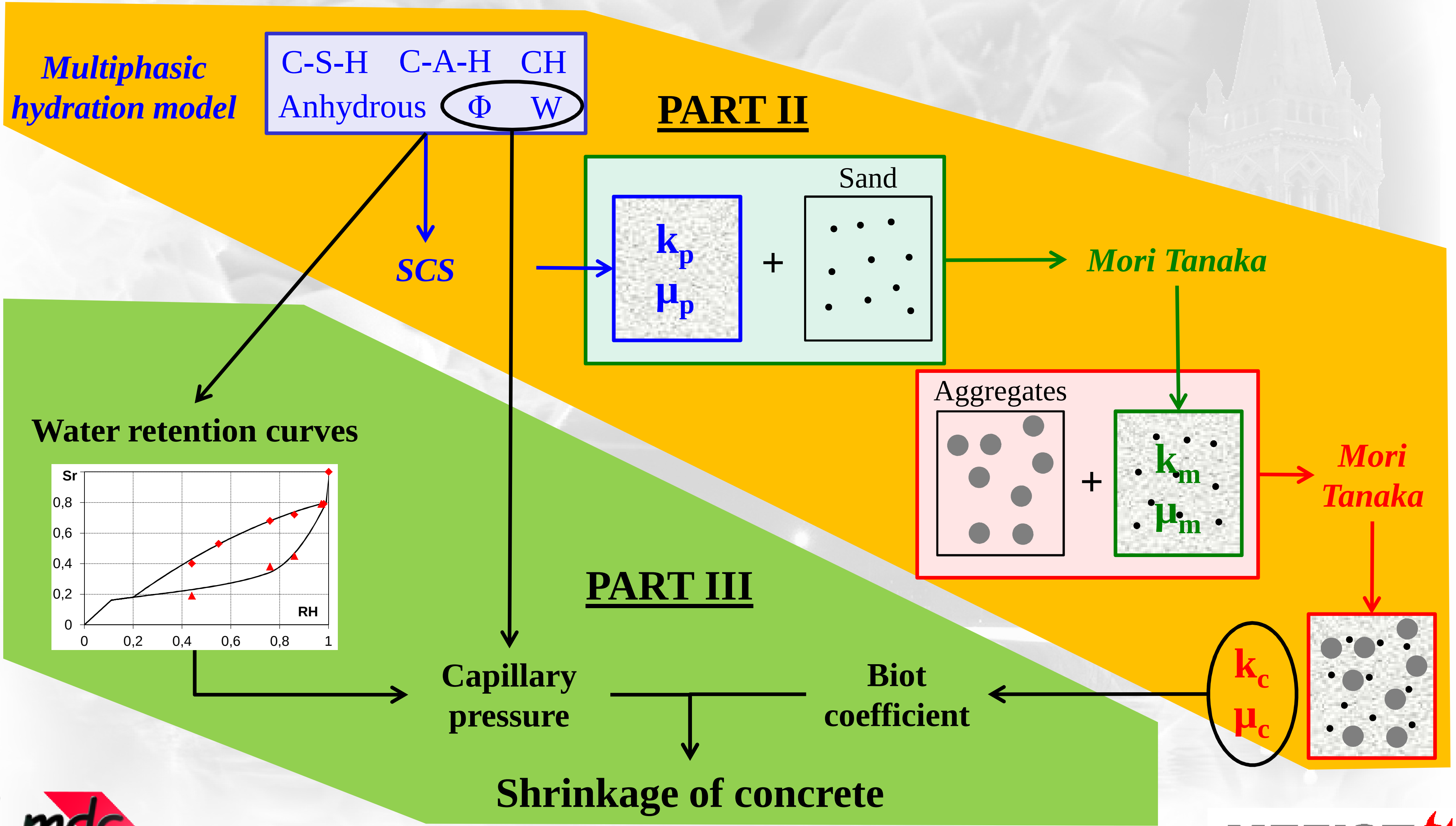
Principal of the multi-scale approach (I/III)

Multi-scale homogenisation for the prediction of elastic properties



Principal of the multi-scale approach (I/III)

Extension to the prediction of shrinkage



I – Principal of the multi-scale approach

II – Prediction of elastic properties

III – Extension to the hydro-mechanical properties

Percolation based multi-scale approach (II/III)

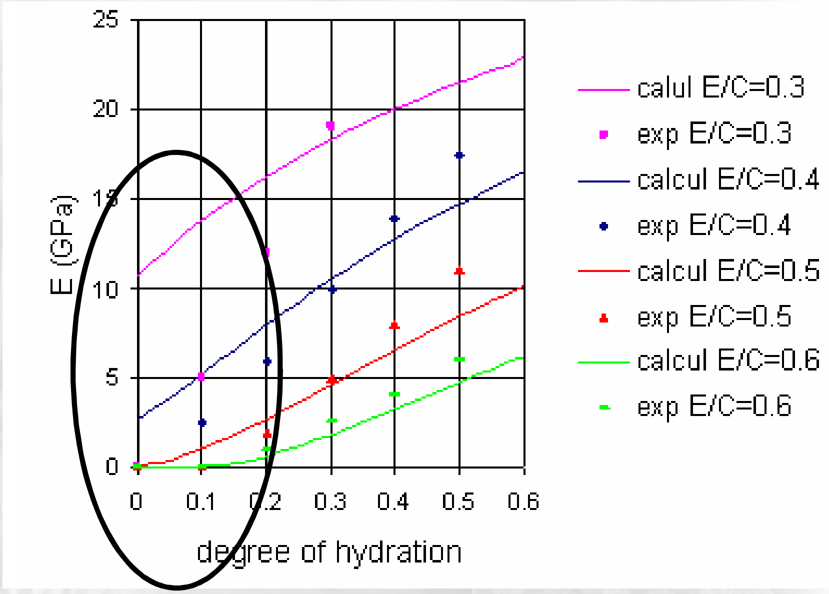
Paste level

Self consistent scheme

=> Percolation for solid fraction > 0.5

Overestimation of the mechanical percolation for low W/C ratios

(interface between solid phases able to transmit hydrostatic and shear stresses)



2 approaches in literature:

- Mechanical percolation algorithm *([Torrenti et al. 2005], [Smilauer et al. 2006])*

=> Unpercolated phases neglected even under hydrostatic stresses

=> Important computing time (incompatibility with structure calculation)

- Shape of inclusions (C-S-H) *[Sanahuja et al. 2007]*

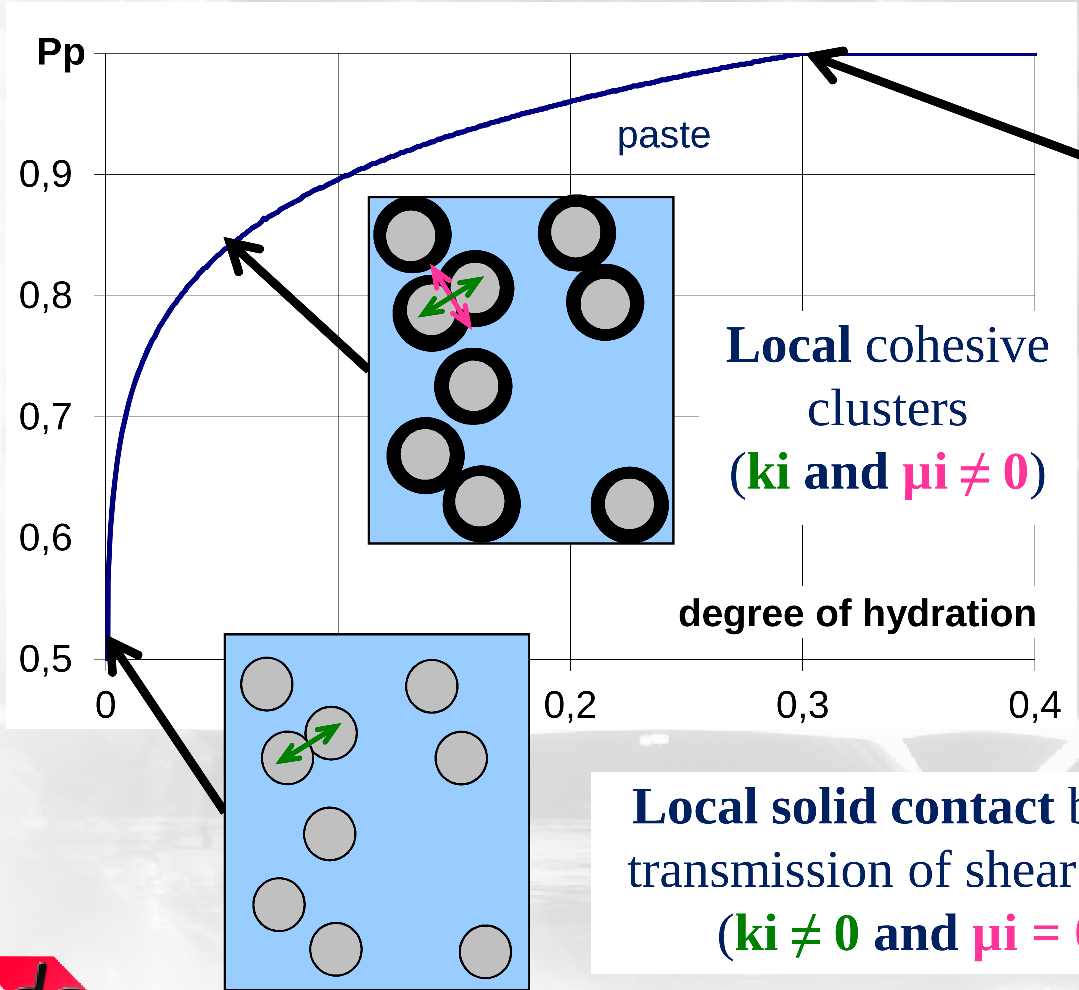
=> Necessity to modify the shape to fit all W/C ratio results

Approach proposed : Percolation probability to separate solid phases into cohesive or non-cohesive according to shear solicitations

Introduction of the percolation probability

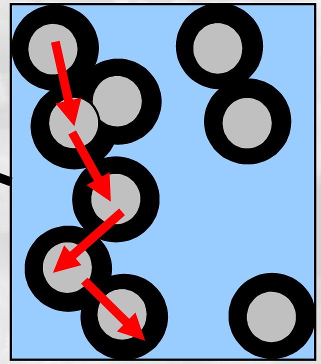
Physical considerations

⇒ Mechanical percolation if solid phases linked with hydrates



Local cohesive clusters (**ki and μi ≠ 0**)

Local solid contact but no transmission of shear stress (**ki ≠ 0 and μi = 0**)



Percolation path (k and μ ≠ 0 on the entire REV)

➔ ***Percolation probability depends on hydration degree***

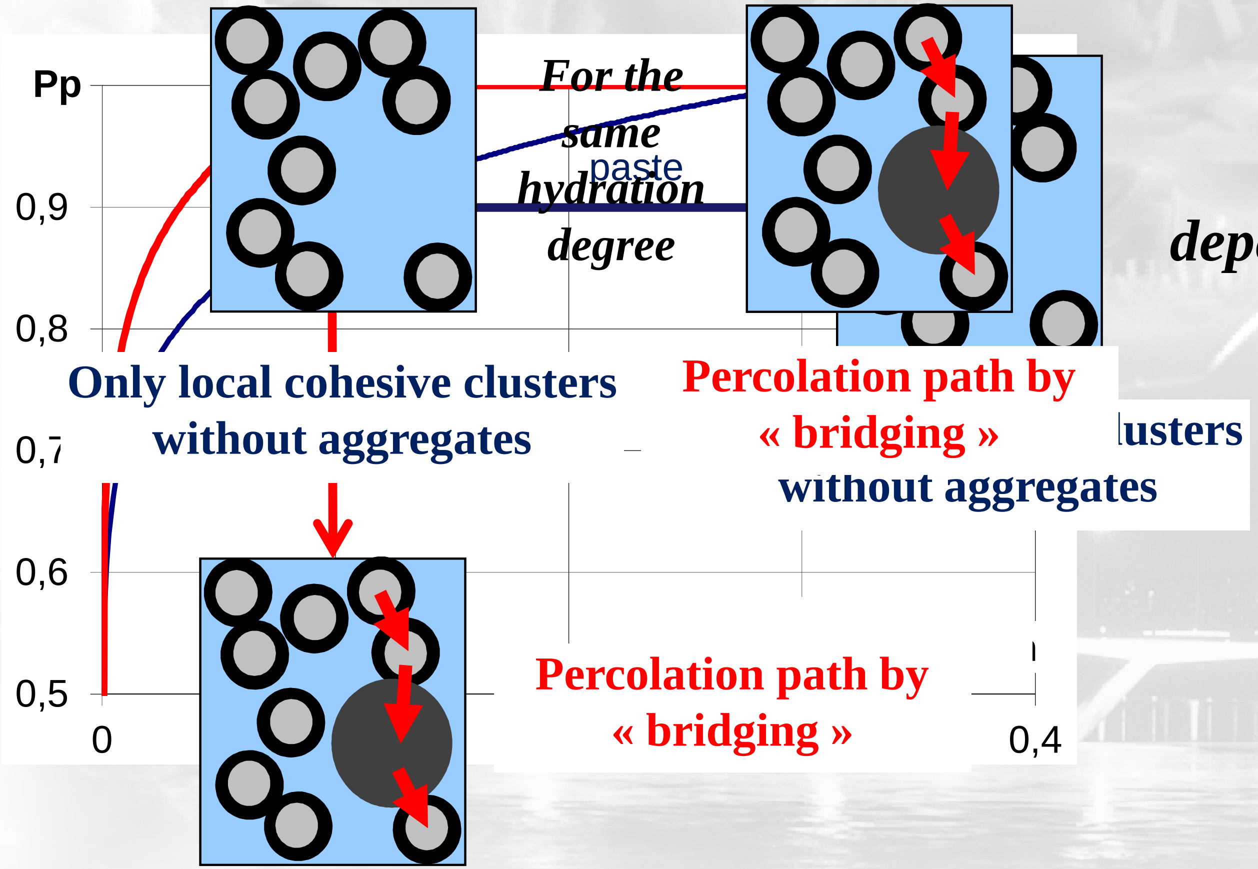
$$P_P = \left(\frac{\alpha}{\alpha_{cr}}\right)^{1/m}$$

Introduction of the percolation probability

Physical considerations

⇒ Mechanical percolation if solid phases linked with hydrates

⇒ "Bridge" effect of aggregates on percolation



➔ ***Percolation probability depends also on aggregate content***

$$P_P = \left(\frac{\alpha}{\alpha_{cr}} \times \frac{1}{1-\phi_g} \right)^{1/m}$$

Percolation based multi-scale approach (II/III)

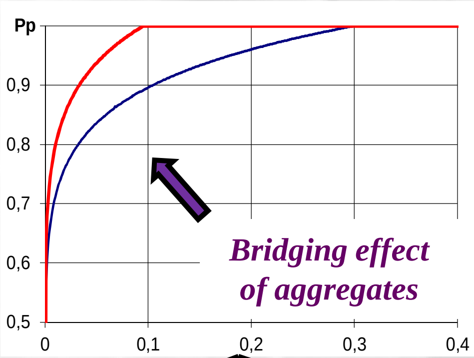
Prediction of paste elastic properties

Multiphasic hydration model

C-S-H	C-A-H	CH
Anhydrous	Φ	W

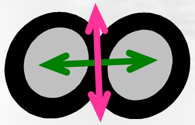
f_i

+ Percolation probability



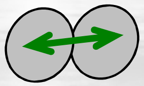
$$f_{i\,perc} = P_P \cdot f_i$$

Percolated *solid phases* ***(ki, µi)***



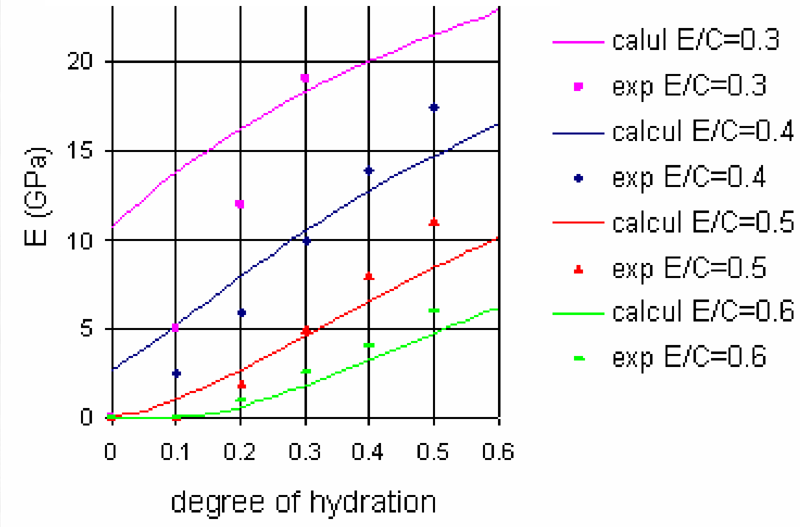
$$f_{i\,perc} = (1 - P_P) \cdot f_i$$

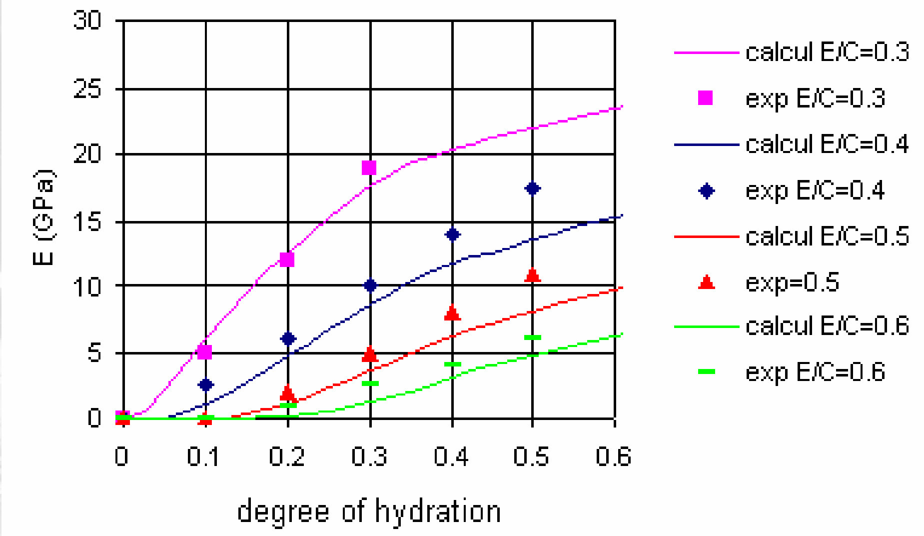
Unpercolated *solid phases* ***(ki, µi=0)***



SCS

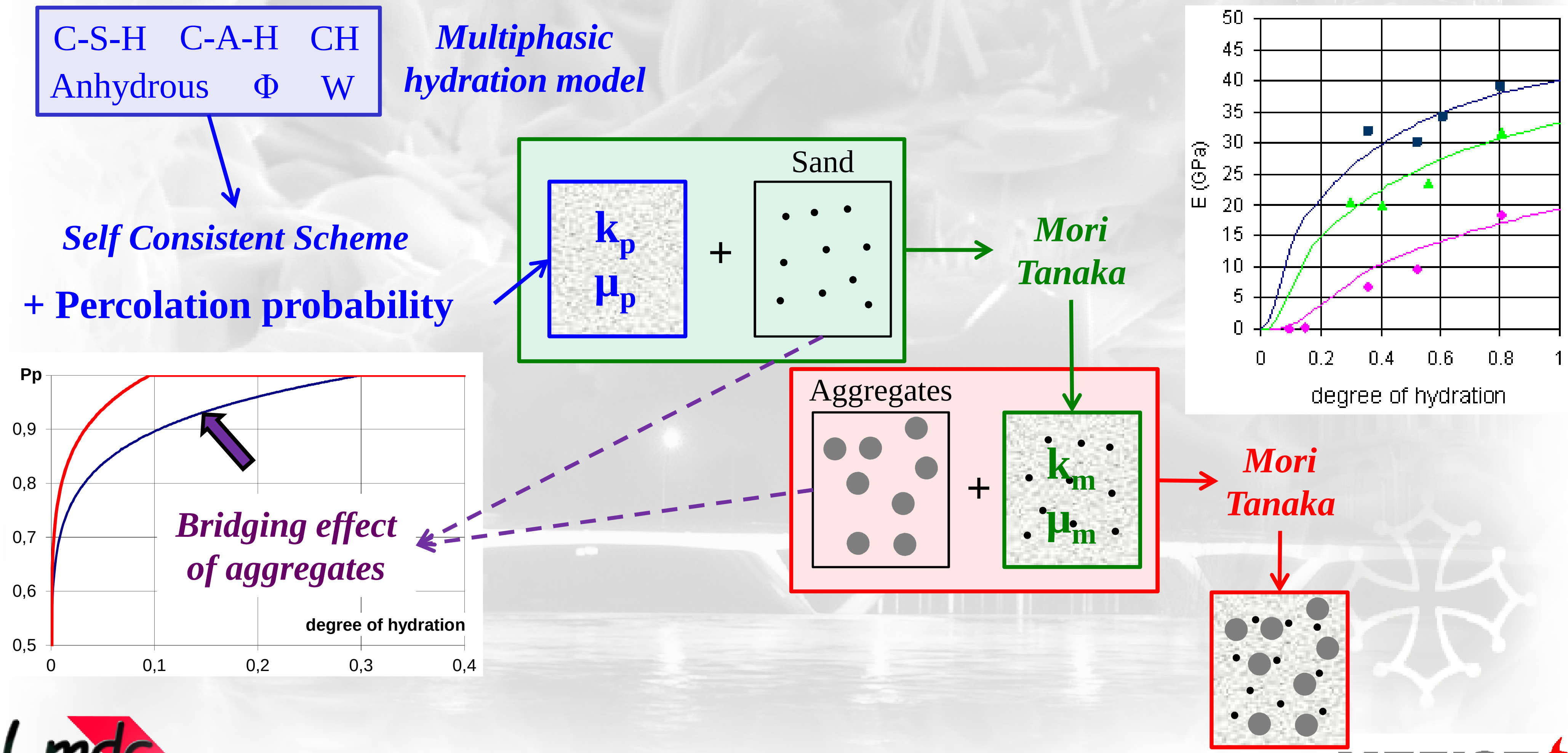
Without percolation





Conclusions on the multi-scale coupled method

- **3 levels with interactions** of mortar and concrete levels on paste
- Original **percolation function** for realistic prediction of percolation development

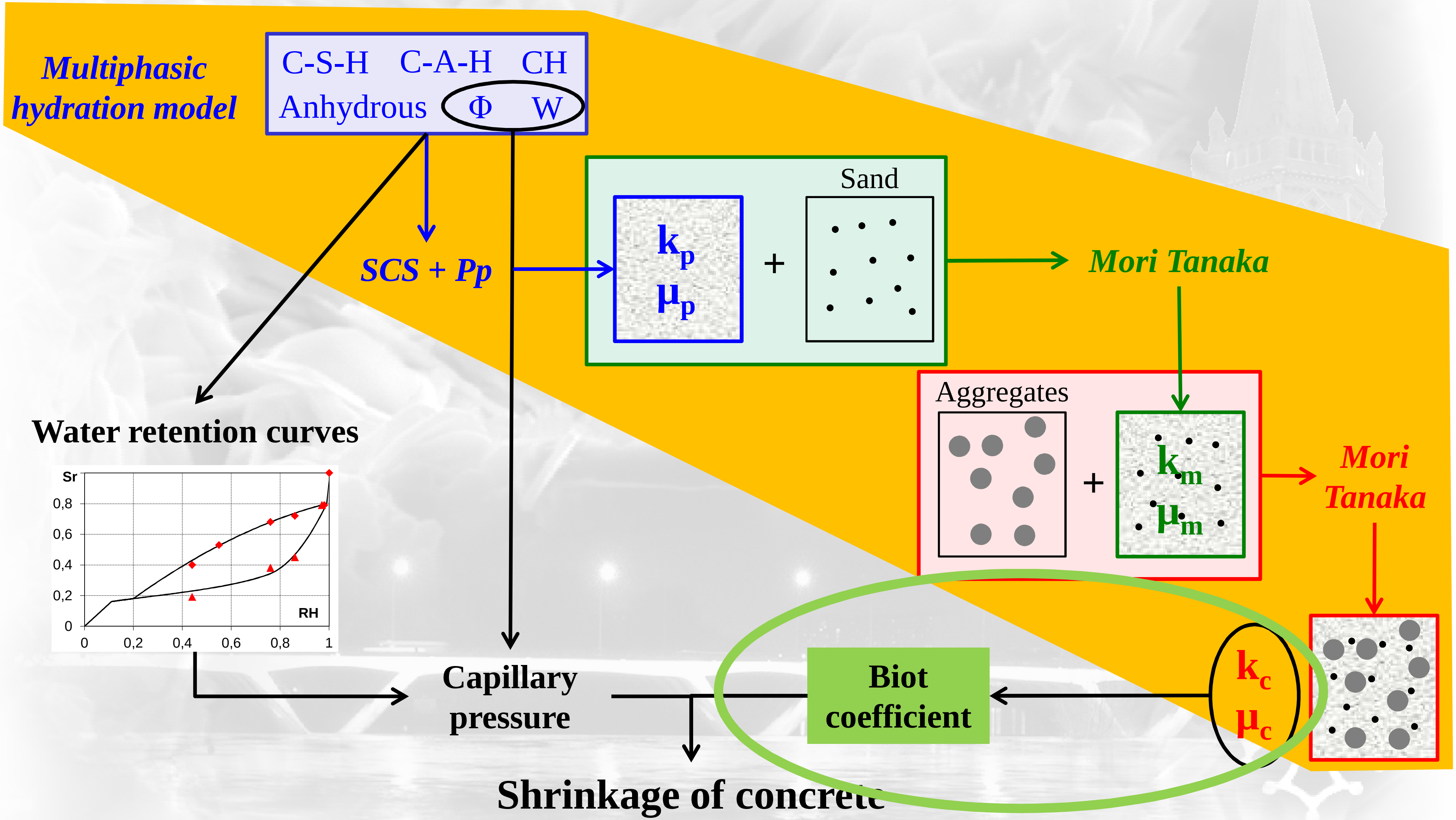


I – Principal of the multi-scale approach

II – Prediction of elastic properties

III – Extension to the hydro-mechanical properties

Extension to the hydro-mechanical properties (III/III)



Extension to the hydro-mechanical properties (III/III)

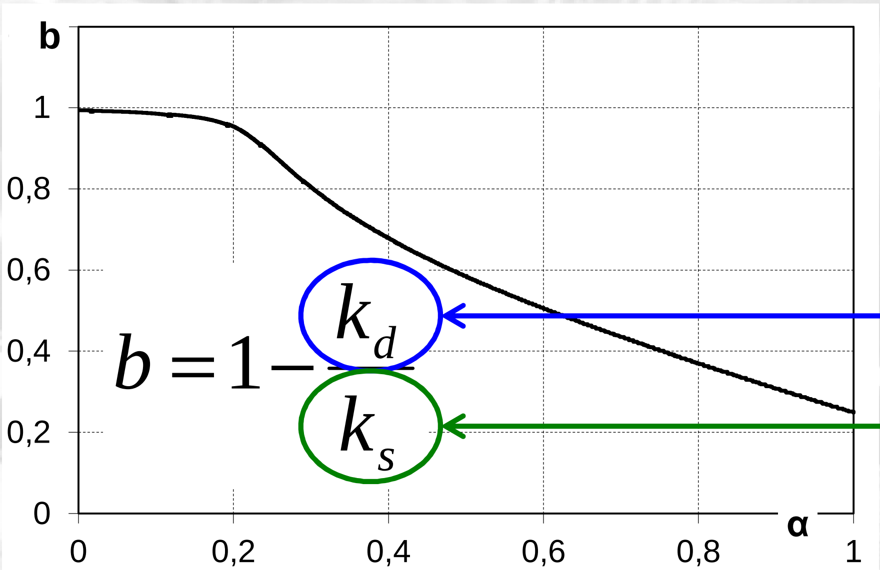
Assessment of Biot coefficient

Application of multi-scale method on drained material

⇒ Compressibility of water taken equal to zero in the homogenisation of paste

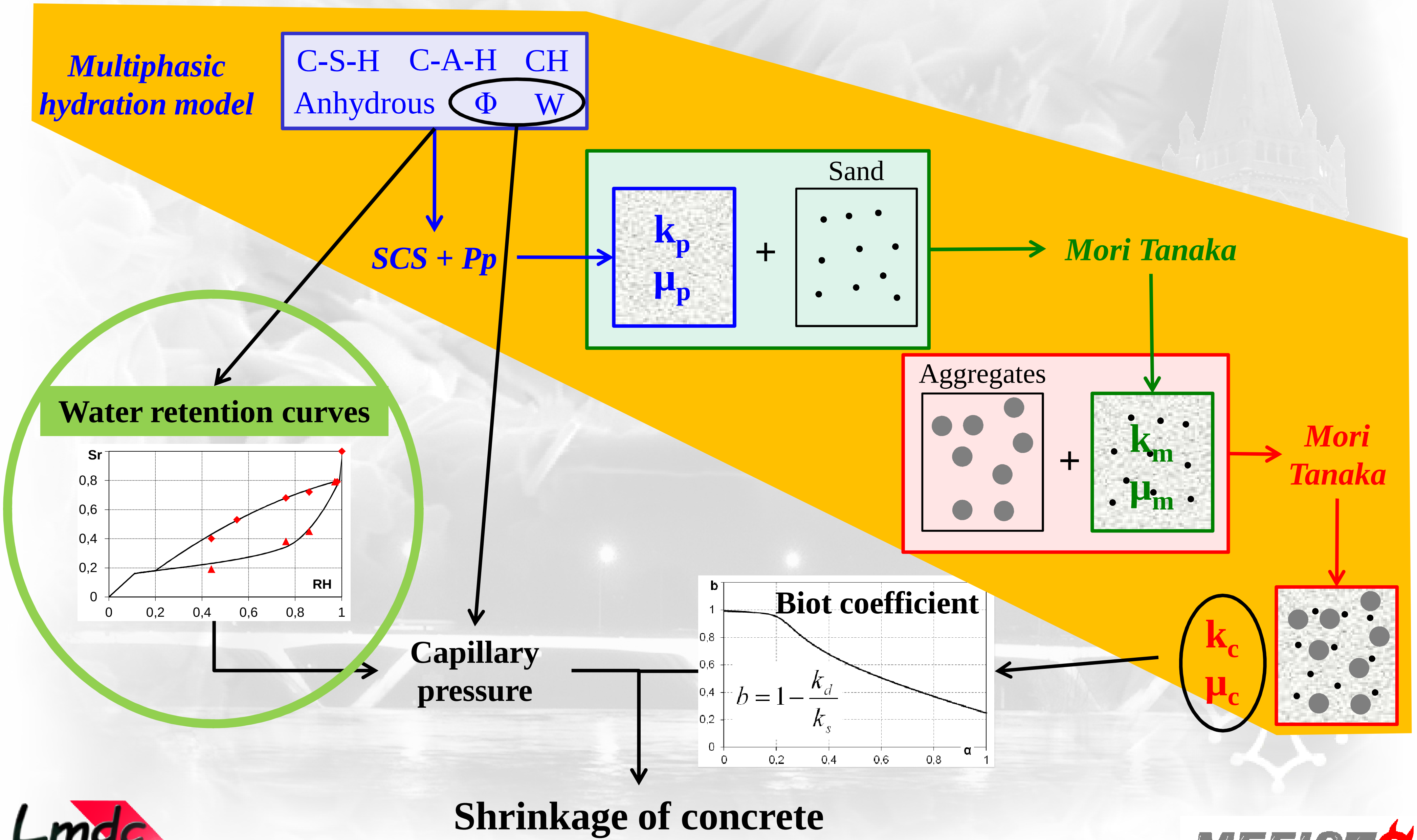
Application of multi-scale method on solid skeleton only

⇒ Water and pore phases not taken into account in the homogenisation of paste



$$b = 1 - \frac{k_d}{k_s}$$

Extension to the hydro-mechanical properties (III/III)

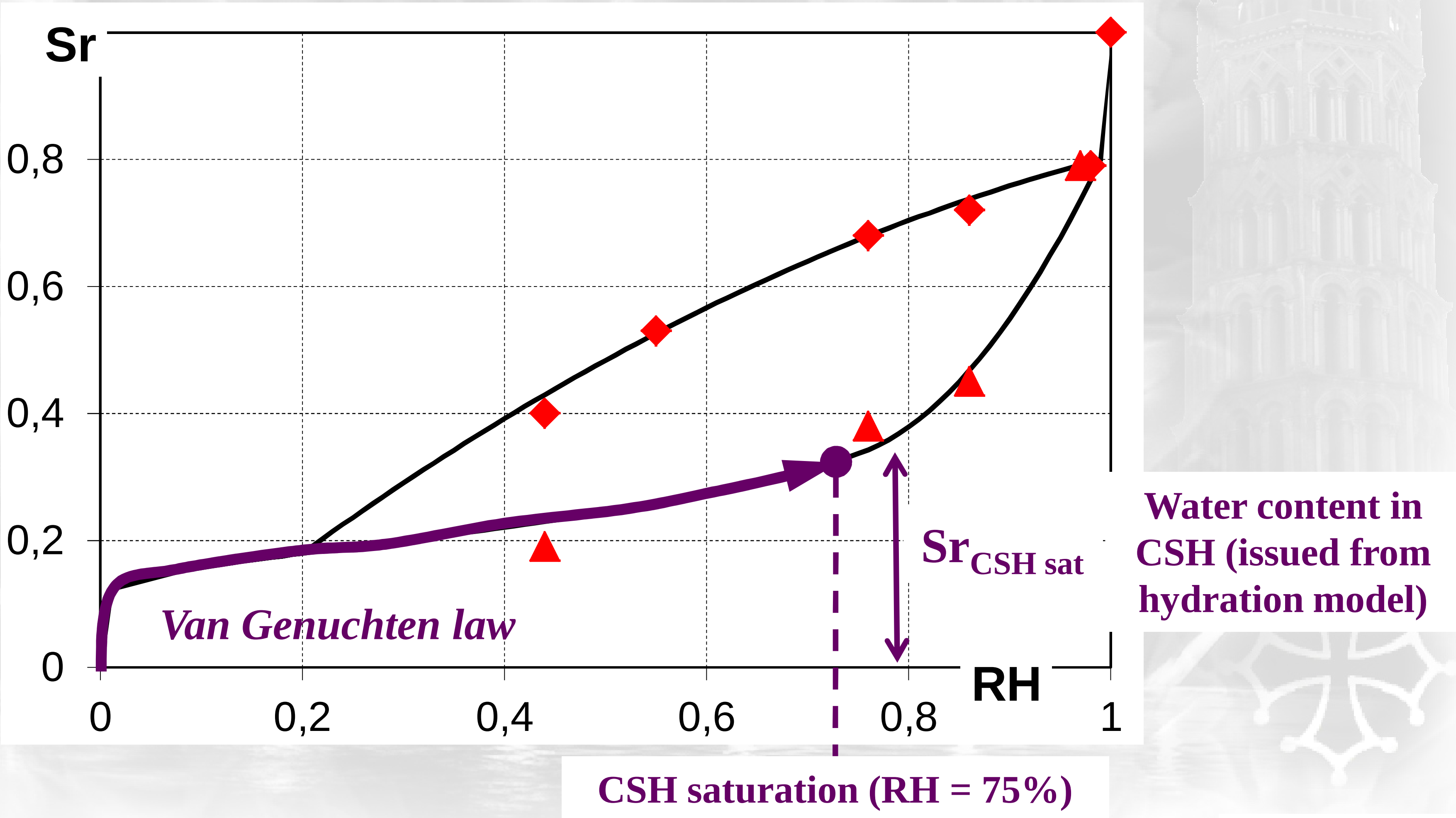


Extension to the hydro-mechanical properties (III/III)

Modelling of water retention curves

Adsorption in cement based materials

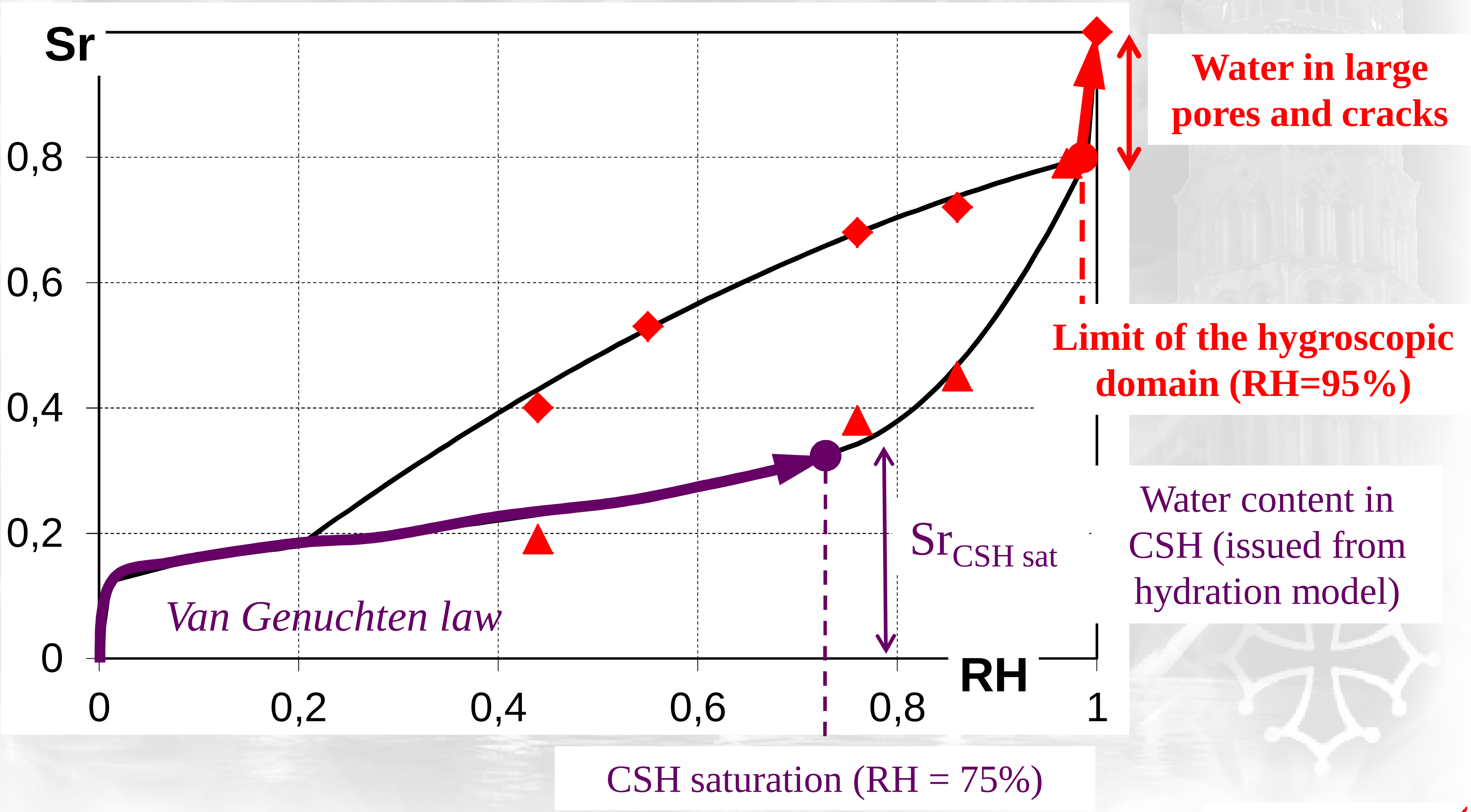
⇒ For **RH<75%** : water in CSH ➔ Van Genuchten adsorption law



Modelling of water retention curves

Adsorption in cement based materials

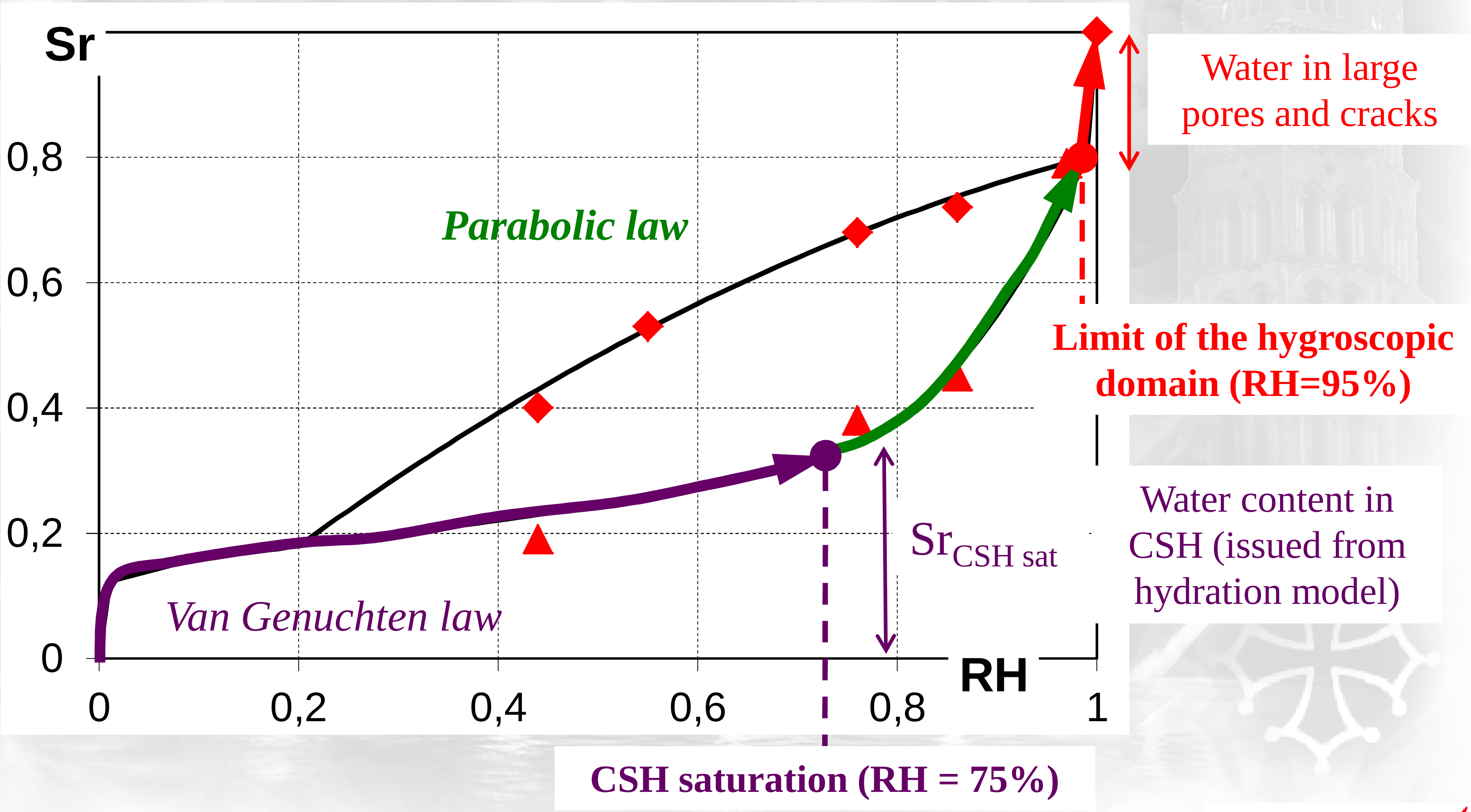
⇒ For **RH>95%** : over-hygroscopic domain (**water in large pores** and cracks)



Modelling of water retention curves

Adsorption in cement based materials

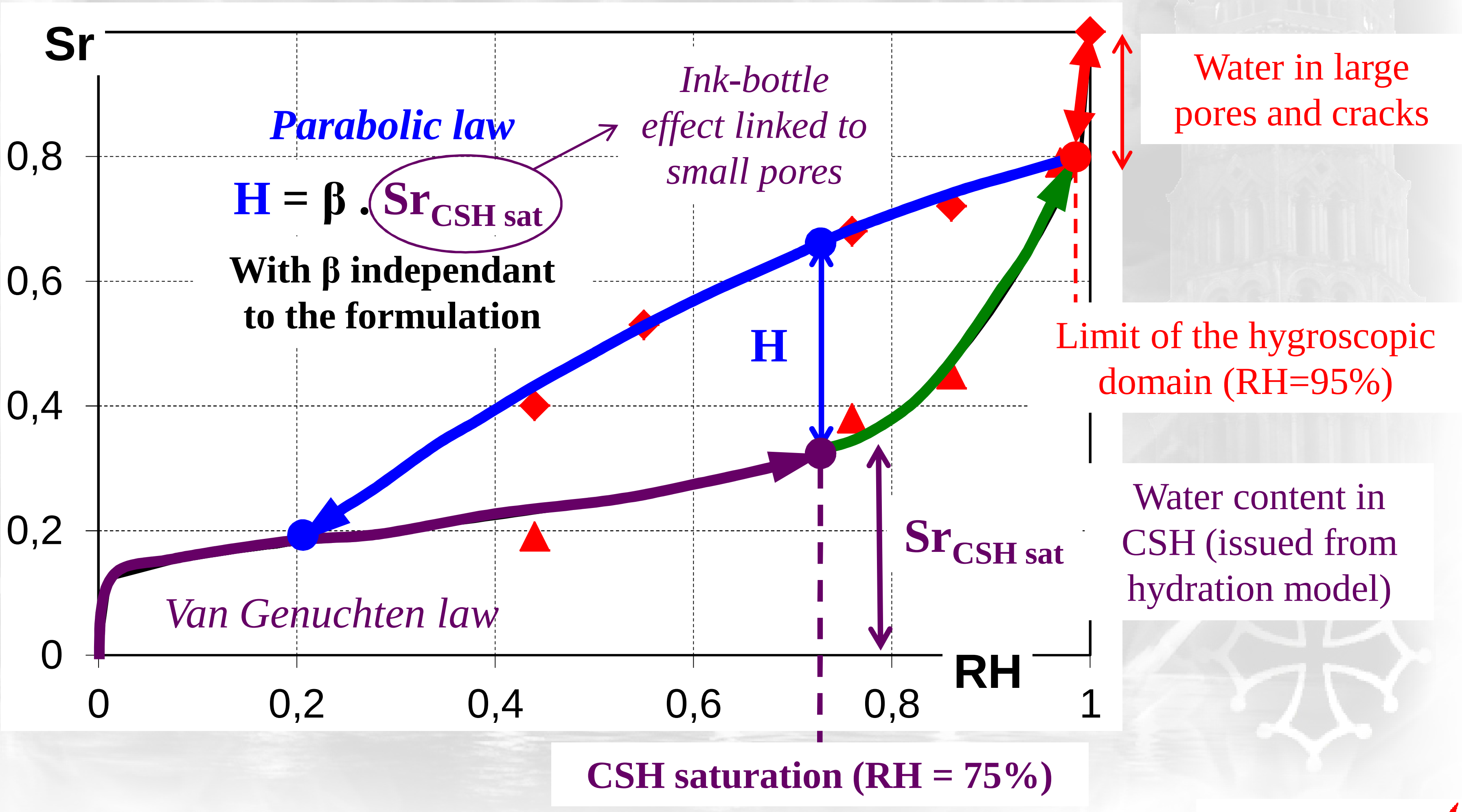
⇒ For **75%>RH>95%** : **Parabolic** law to fit the 2 Sr values and gradient at 75%



Modelling of water retention curves

Desorption in cement based materials

⇒ **Hysteresis** phenomenon experimentally observed **between 20% and 95% RH**



Extension to the hydro-mechanical properties (III/III)

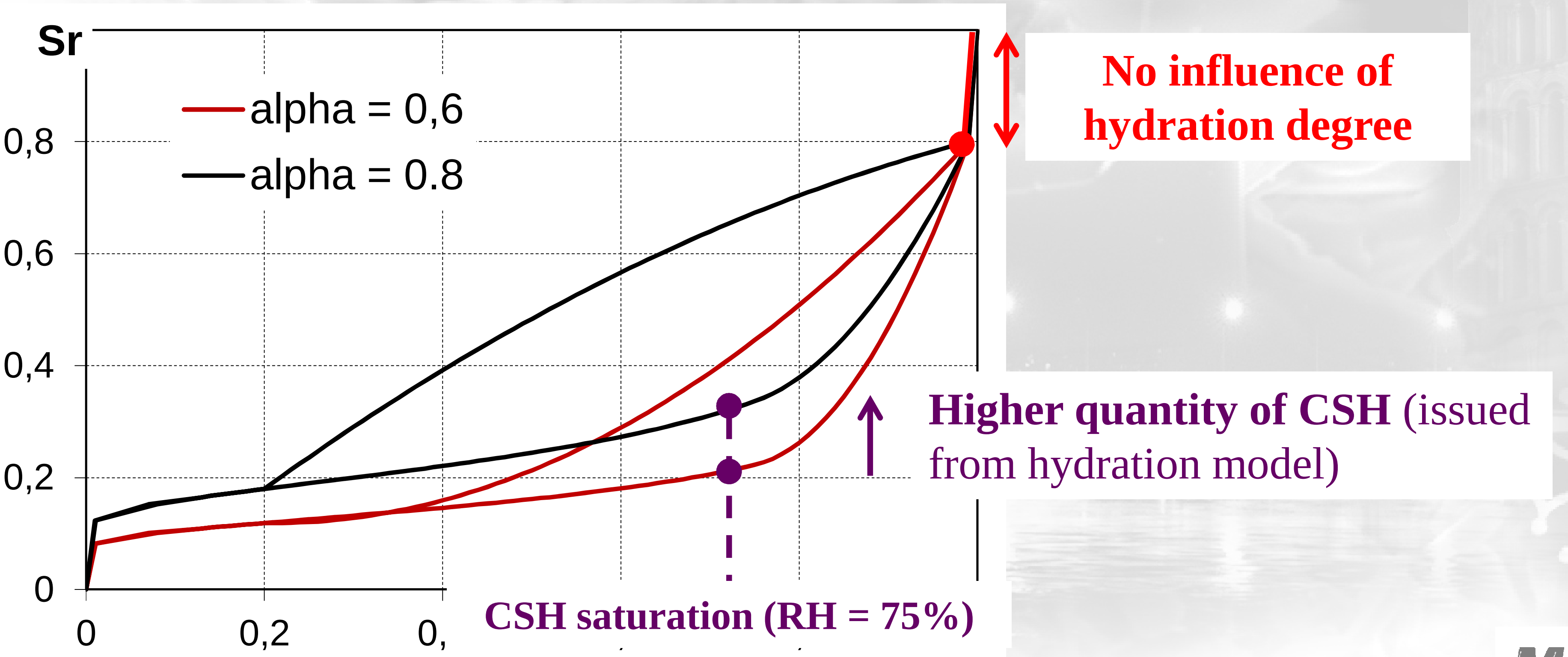
Modelling of water retention curves

Effect of hydration

Few results in literature: observation of more water content for a same relative humidity if hydration degree increases

⇒ More water content at CSH saturation (higher CSH quantity from hydration model)

⇒ No influence on the water in large pores and cracks



Extension to the hydro-mechanical properties (III/III)

Modelling of water retention curves

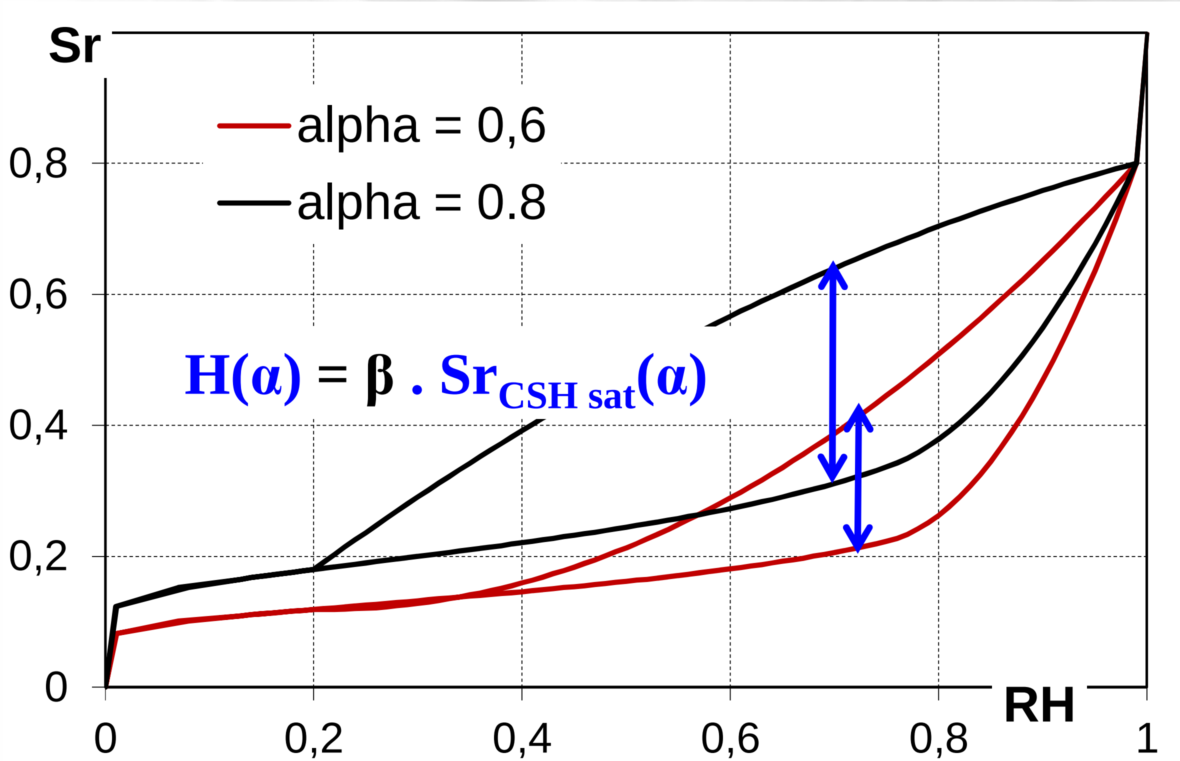
Effect of hydration

Few results in literature: observation of more water content for a same relative humidity if hydration degree increase

⇒ More water content at CSH saturation (higher CSH quantity from hydration model)

⇒ No influence on the water in large pores and cracks

⇒ More hysteresis (but β not influenced by hydration degree)



Higher quantity of CSH predicted by **hydration** automatically leads to:

- higher water for a same RH
- higher hysteresis

➔ ***Water retention model seems to be adapted to different hydration degree without modifying parameters***

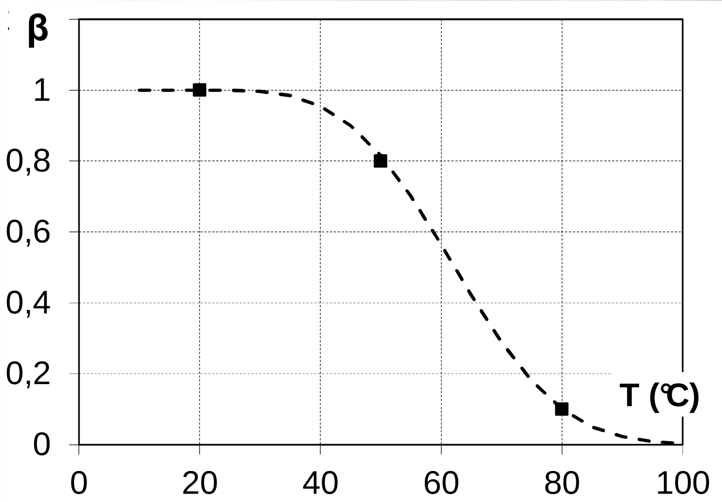
Modelling of water retention curves

Effect of temperature

Experimental results on the same concrete at 20, 50 and 80°C

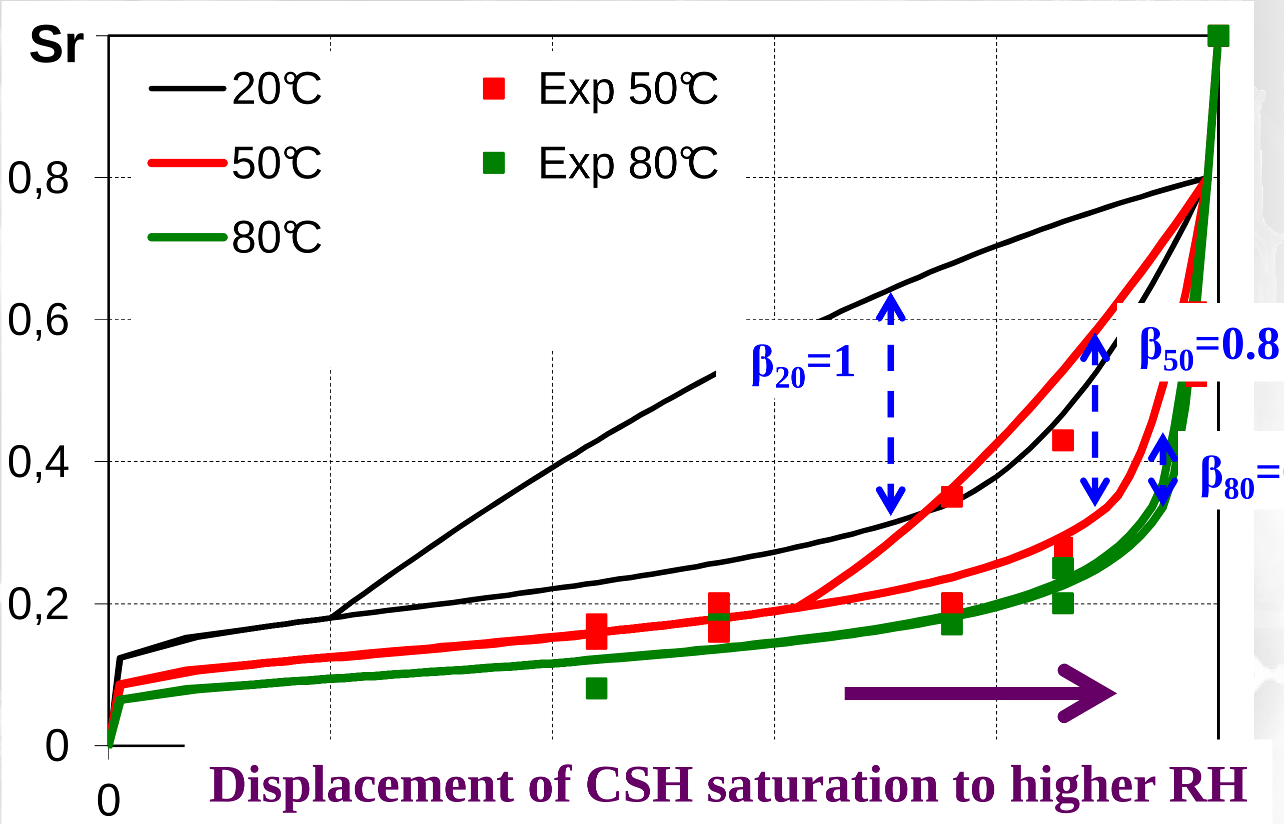
⇒ Less water content in hygroscopic domain

⇒ Less hysteresis (β decreases with temperature)

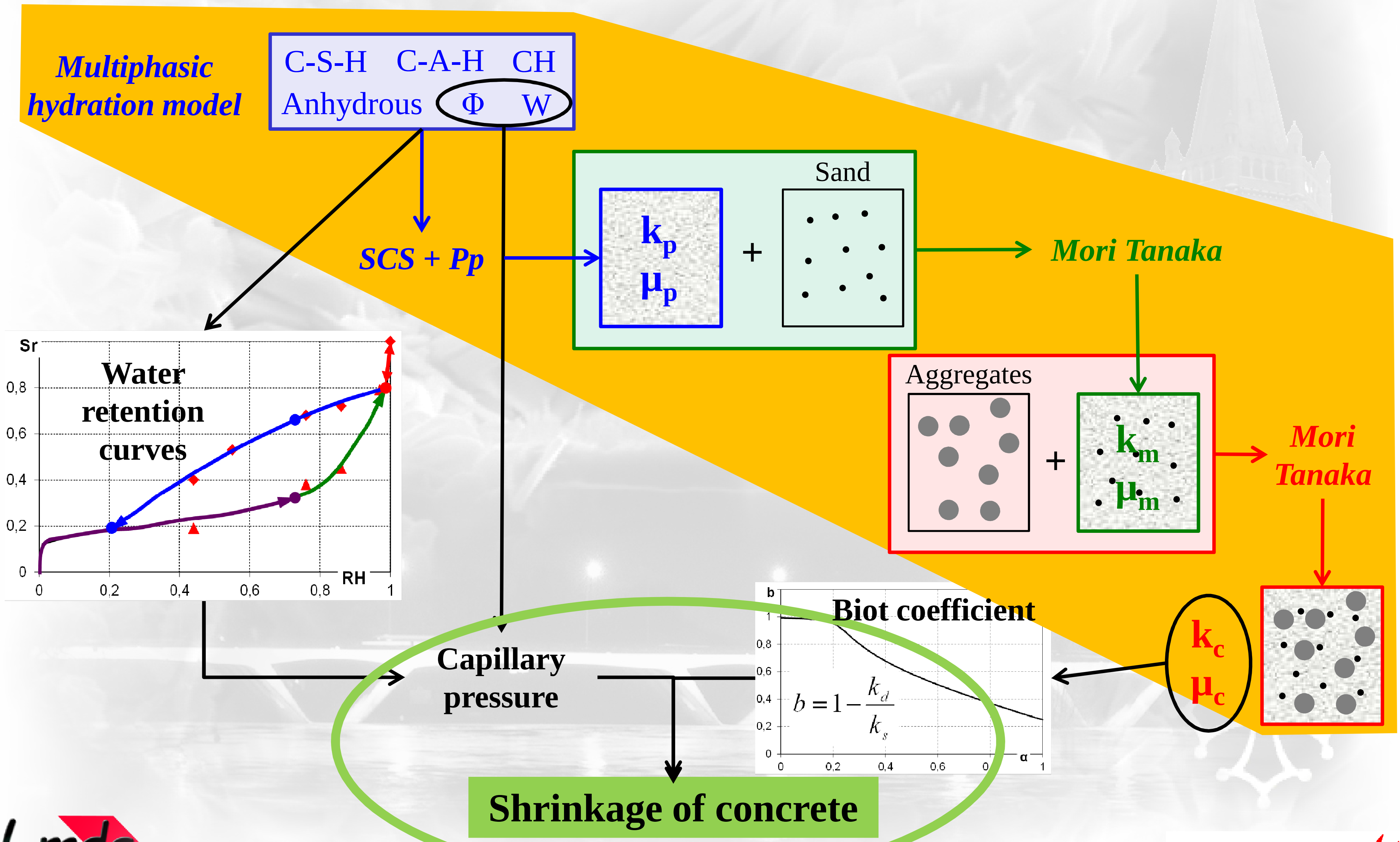


$$\beta = \exp\left(-\frac{1}{4}\times\left(\frac{3000}{T_{ref}}-\frac{3000}{T}\right)^4\right)$$

$$\beta = 1 \quad \text{for } T < 20°C$$



Extension to the hydro-mechanical properties (III/III)



Extension to the hydro-mechanical properties (III/III)

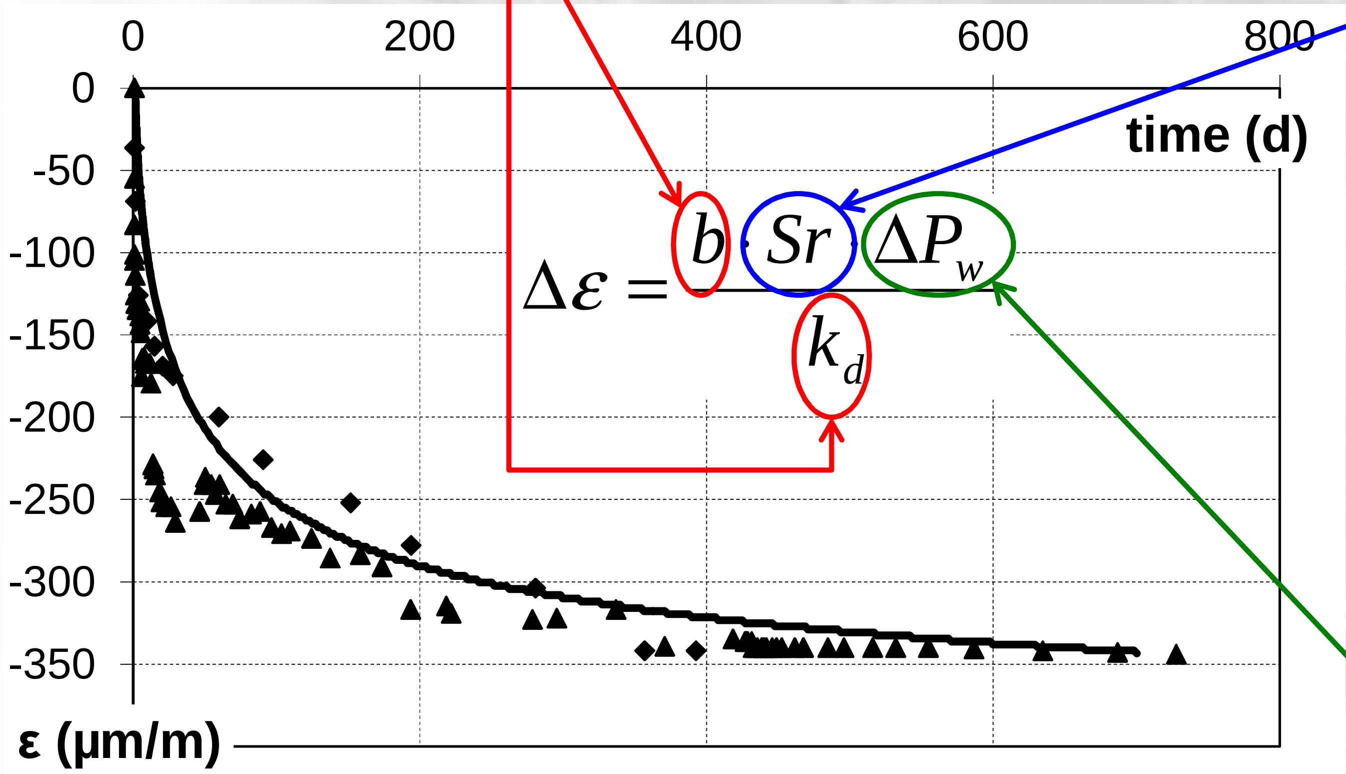
Prediction of autogenous shrinkage

Simplified shrinkage prediction: only elastic strain under water pressure

➔ Coupling between creep and shrinkage: see presentation *Sellier et al.*

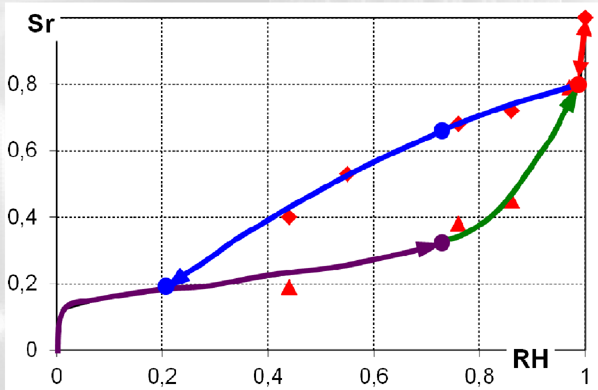
« Coupled level » homogenisation scheme with percolation

Multiphasic hydration model



$$\Delta\varepsilon = \frac{b \cdot Sr \cdot \Delta P_w}{k_d}$$

Water retention curve model



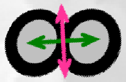
$$P_w = \frac{\rho_w RT}{M_w} \cdot \ln(RH)$$

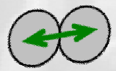
Conclusions

Closure remarks

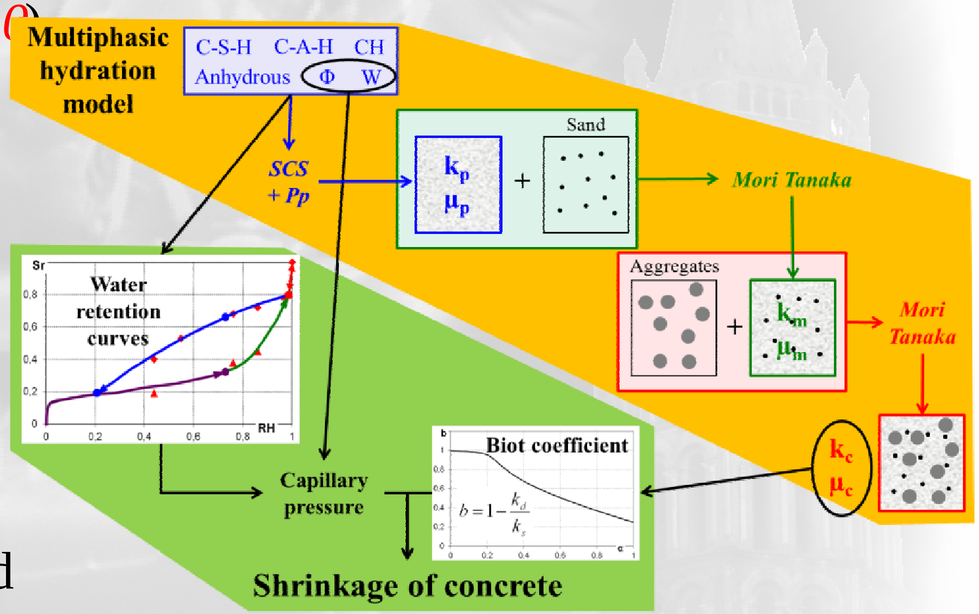
• Original 3 coupled level method

➔ Percolation probability to separate solids into cohesive (k_i,μ_i) and non-cohesive (k_i, $\mu_i=0$)





➔ Interaction between levels due to the "bridging effect" of aggregates



• Extension to the hygro-mechanical properties

➔ Biot coefficient assessment by 2 applications of multi-scale method developed in Part. 1

➔ Model of water retention curves based on hydration predictions (*effect of hydration and temperature included without re-fitting*)

Perspectives:

- More investigate the capability of hydro-mechanical properties model (water retention curves)
- Investigate the evolution of concrete thermal dilatation at early age

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