



WEAK COUPLING BETWEEN A DISCRETE ELEMENT MECHANICS MODEL AND A NUMERICAL FLUID MECHANICS MODEL FOR THE ASSESSMENT OF AIR LEAKS IN CRACKED REINFORCED CONCRETE WALLS

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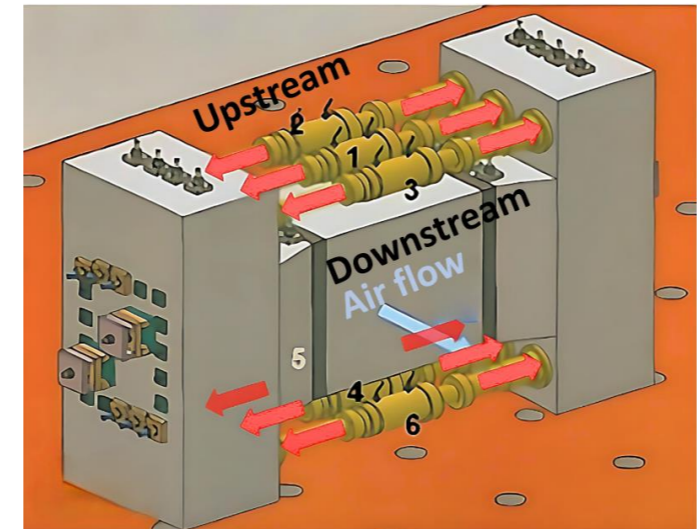
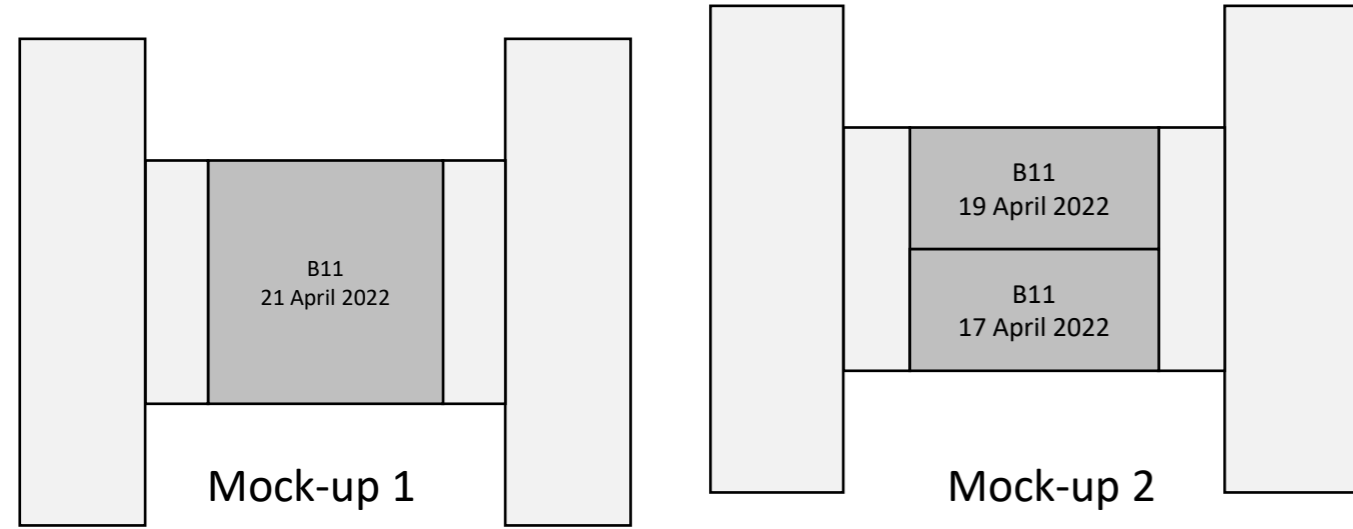
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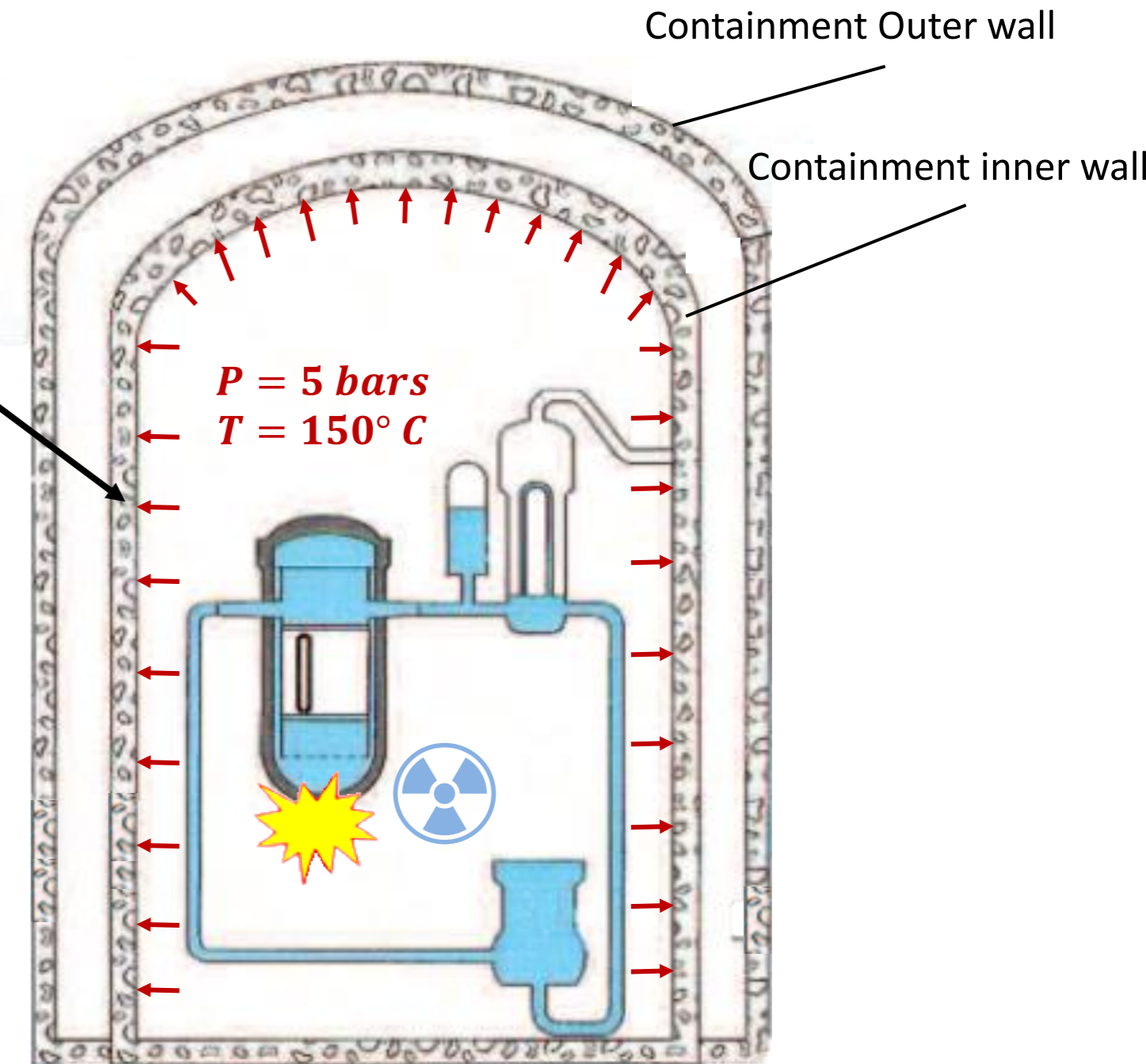
- Leak-tightness of 1300 MWe and 1450 MWe PWR containments is provided by the inner reinforced and prestressed concrete wall and the ventilation system.
- The leakage rate is significantly affected by characteristics of the cracks (such as the crack opening).
- COBRA program is made to enhance our understanding for the estimation of air/air-vapor leakage under sever accident conditions.
- Two mock-ups with type of concrete used for the Zone Of Interest (ZOI) is B11, the same one used for some French NPP.

Severe Accident (SA)

- Core melt down
- Release of radioactive elements out of containment inner wall



90 cm

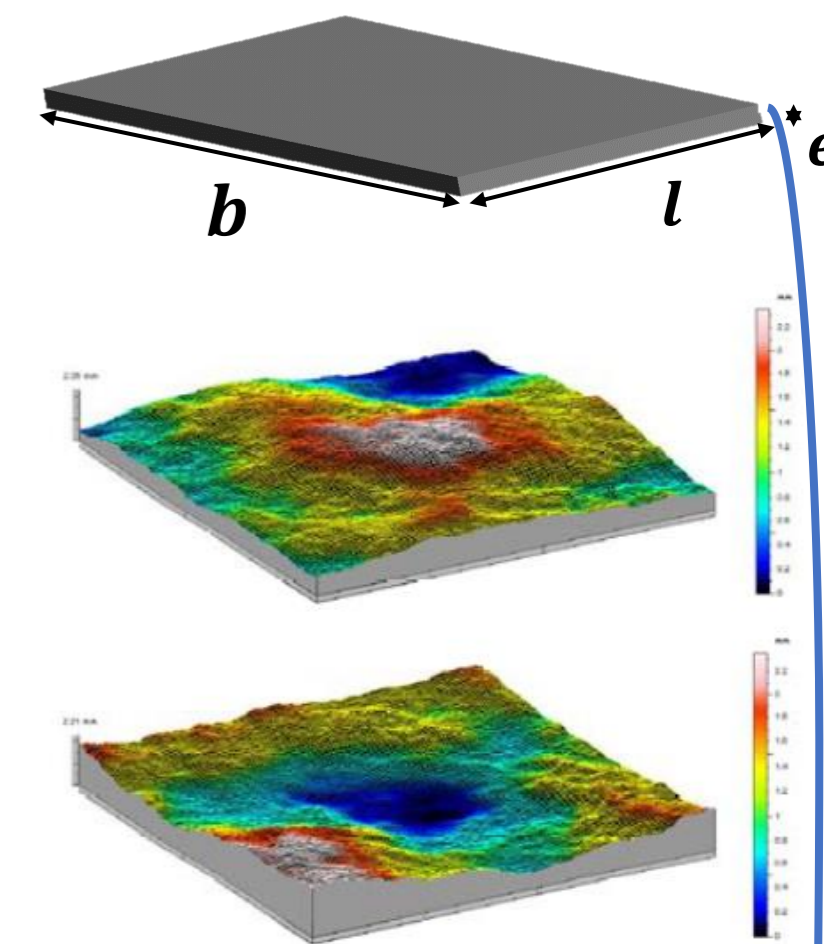


COBRA, French acronym for « **CO**nfinement of **R**eactor **B**uilding in **A**ccident **C**ondition ».

Can more quantitative descriptions of crack characteristics enhance leakage rate predictions?

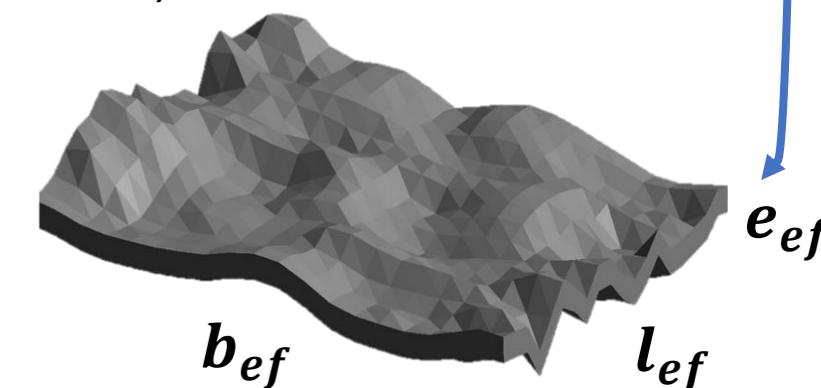
Transfer modelling strategies through a cracked medium:

<ul style="list-style-type: none"> ❖ Member scale description of crack characteristics (mean crack opening, extent, path) : <ul style="list-style-type: none"> • Continuous approach: depends on damage level of the elements; • Discrete approach: based on Poiseuille's law. 	<ul style="list-style-type: none"> ▪ High uncertainty in leakage prediction; ▪ Very low computational cost
<ul style="list-style-type: none"> ❖ Crack scale description of crack characteristics obtained: <ul style="list-style-type: none"> • Experimentally using micro computed tomography and digital microscope measures of concrete surfaces; • Spectral analysis for surface tomography characterization. 	<ul style="list-style-type: none"> ▪ Lower uncertainty in leakage prediction; ▪ High computational cost ▪ Difficult/impossible to measure



[R Zimmerman et al., 2004]

(illustration)



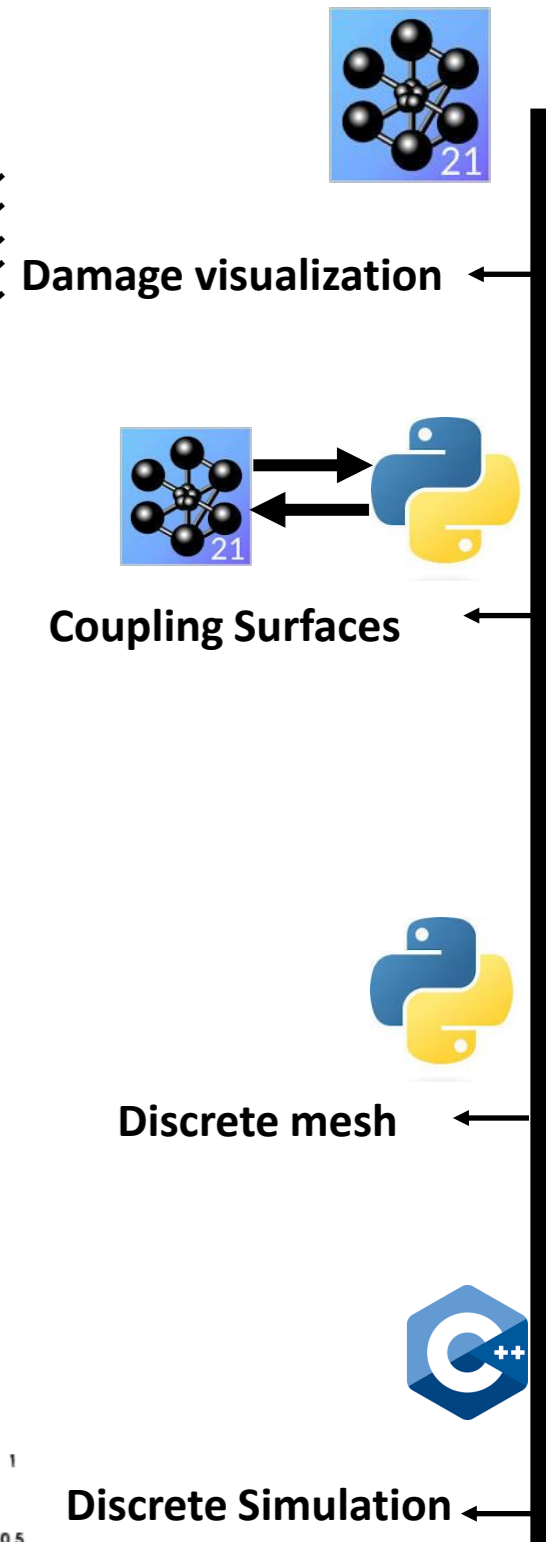
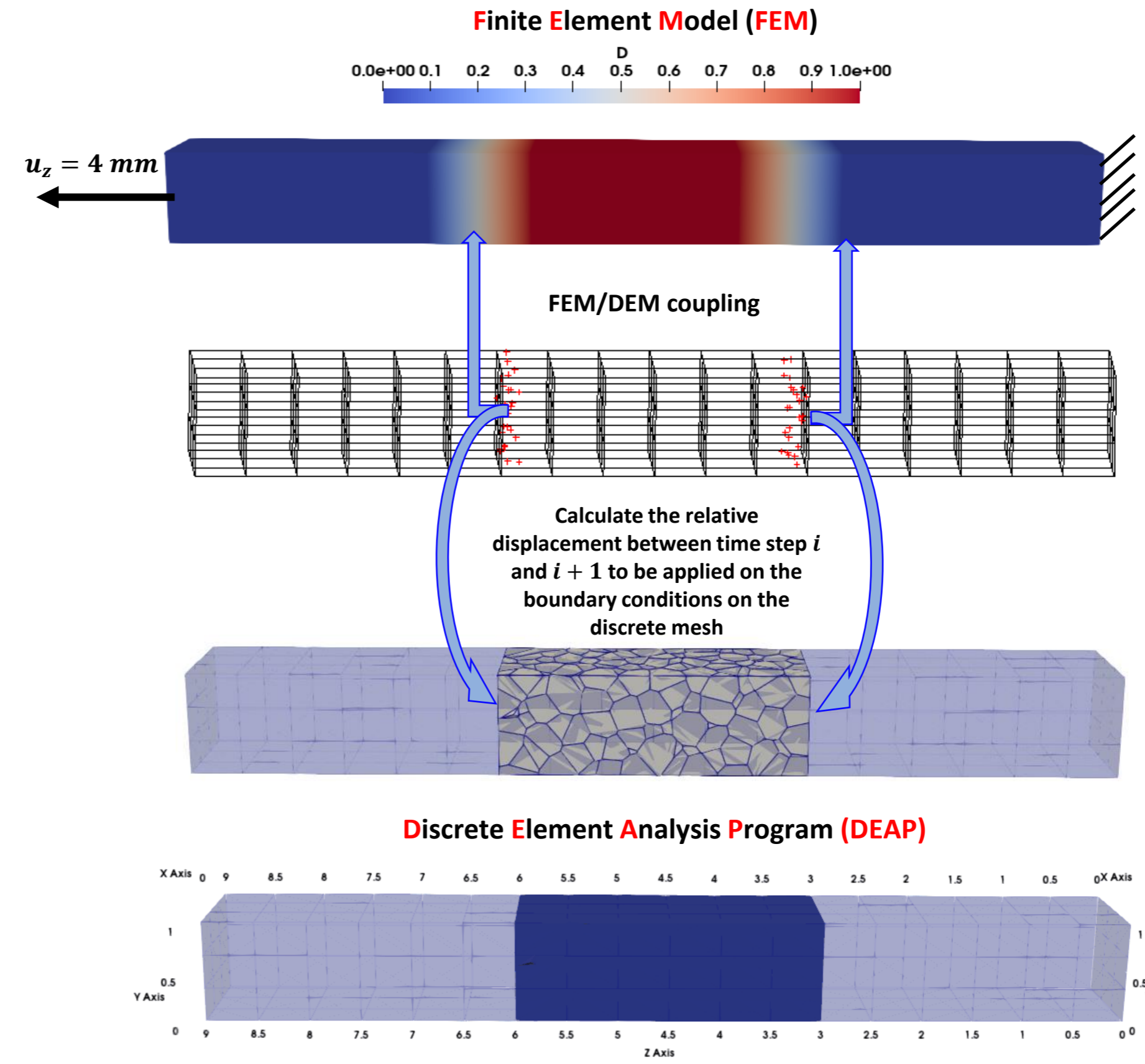
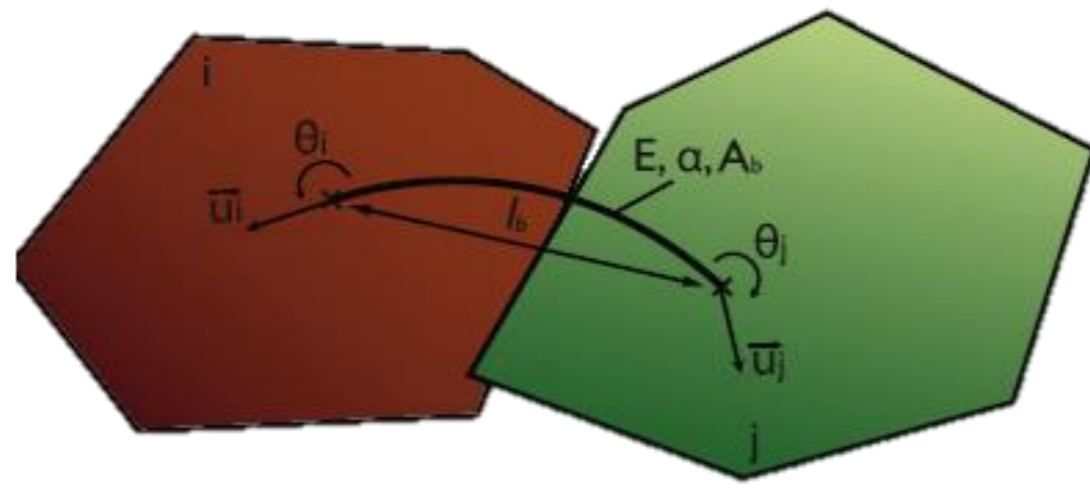
Goal: develop a tool which allows to obtain a realistic crack geometry based on mechanical simulations and used directly in CFD simulation.

Full Chain-Model:

- ❖ Perform **FEM simulations** using damage models (CONCYC model [Richard et al. 2015]);
- ❖ Carry out parameter identification between FEM and DEM to have the same mechanical properties;
- ❖ Perform **weak FEM/DEM coupling** [Cécile Oliver-Leblond, 2013].

Fracture criteria

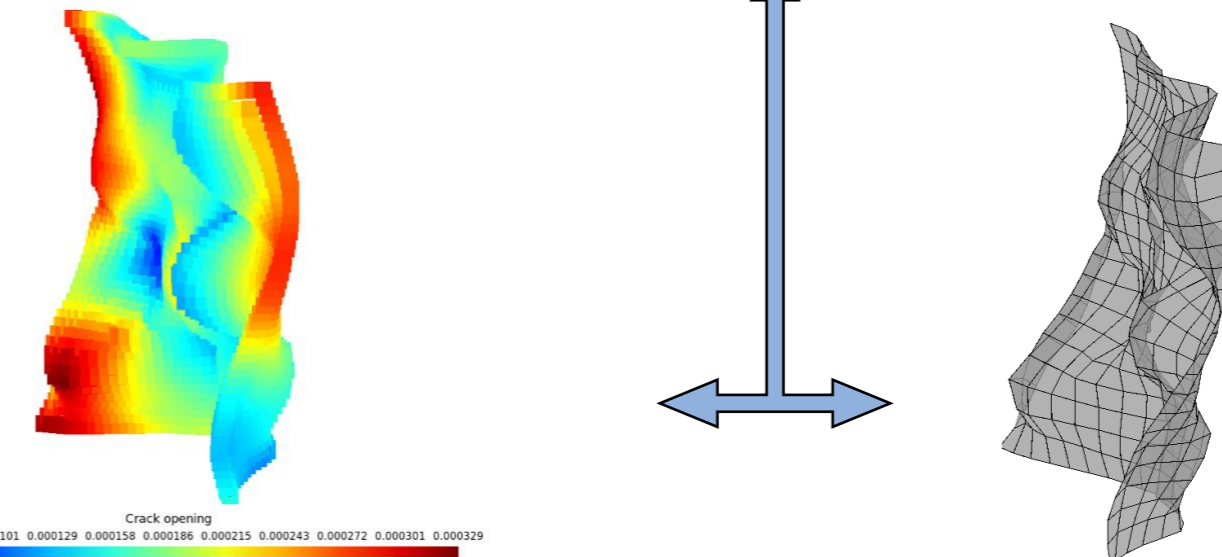
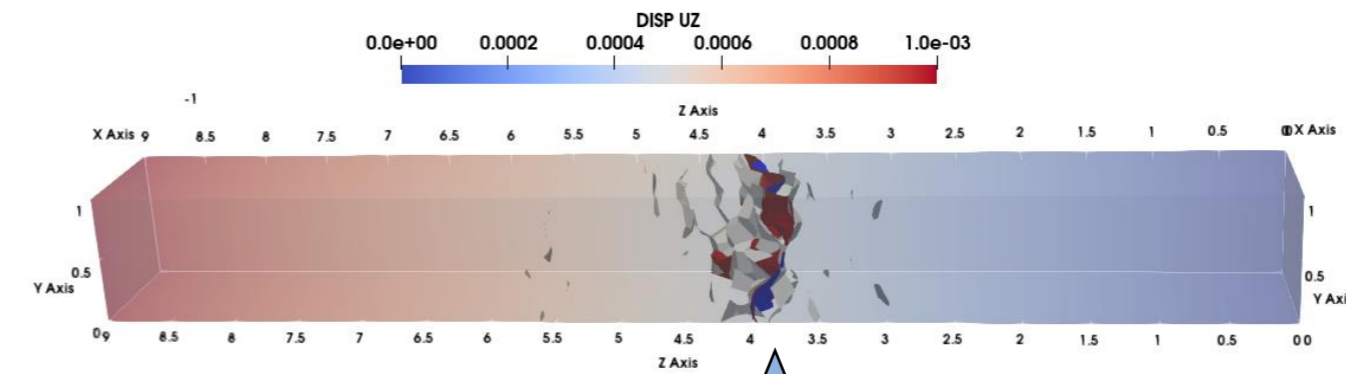
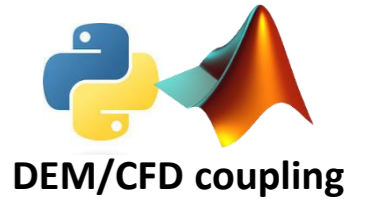
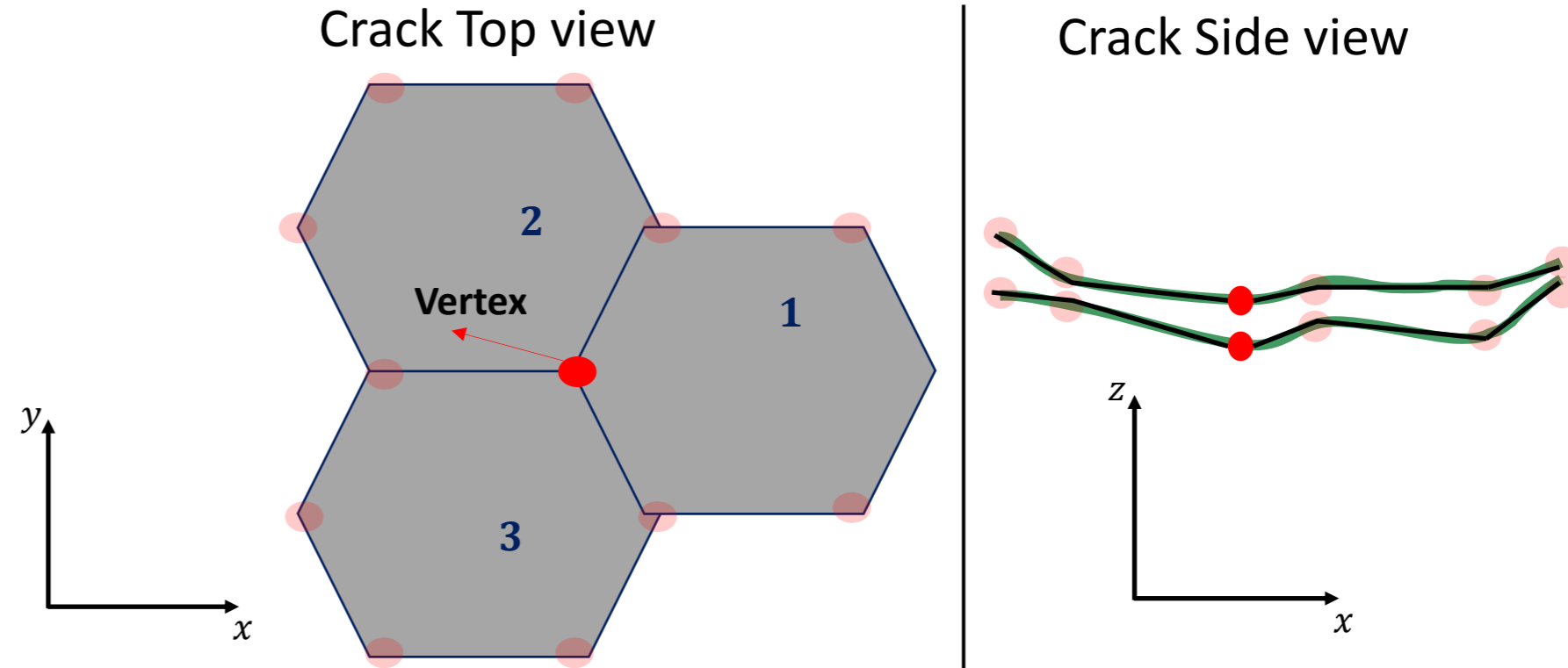
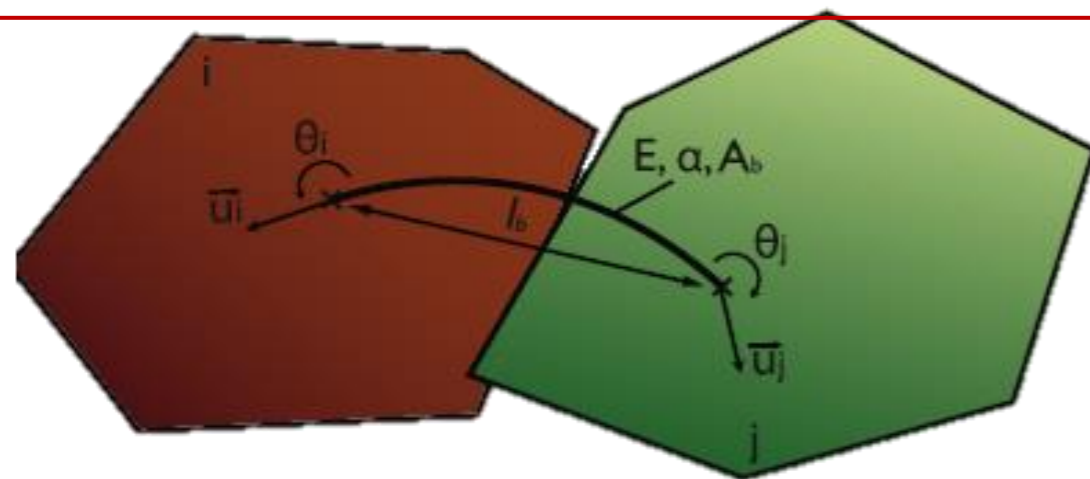
$$P_{ij} = \left(\frac{\epsilon_{ij}}{\epsilon_{cr,ij}} \right) + \left(\frac{|\theta_i - \theta_j|}{\theta_{cr,ij}} \right) \geq 1$$



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- ❖ Make **DEM/CFD coupling** based on **graph theory** to obtain a macro crack geometry that can be imported to CFD;
- ❖ Perform **CFD simulations** to obtain fluid leakage



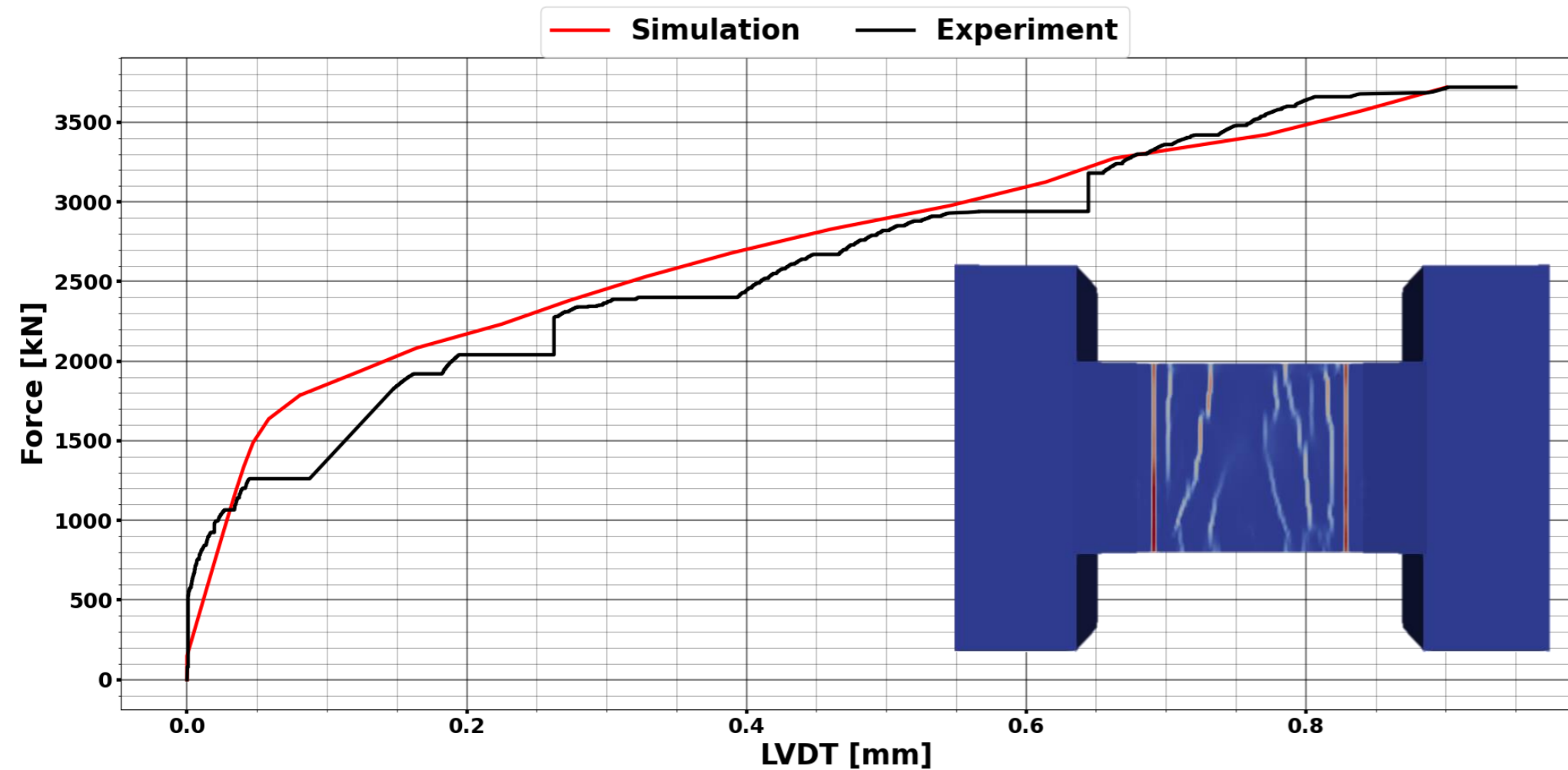
FEM/DEM coupling

❖ FEM COBRA Calibration

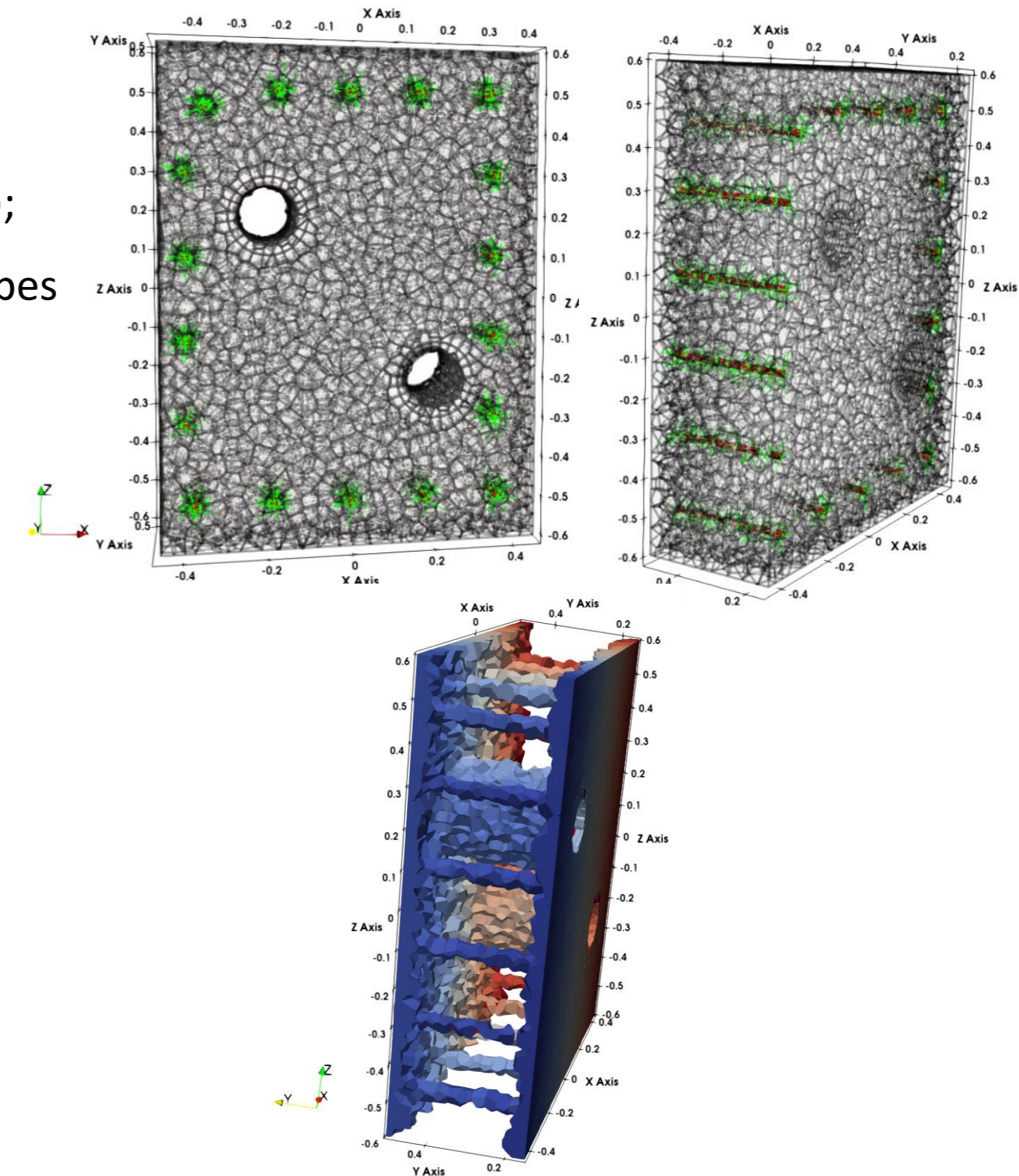
- Scale effect;
- Random variability of concrete ;
- Steel concrete bond slip ;
- Concrete constitutive behavior.

❖ The boundary conditions are imposed displacements imported from FEM on:

- The two coupling surfaces;
- Steel centers (represented in red);
- The two prestressing cylinders tubes surfaces.



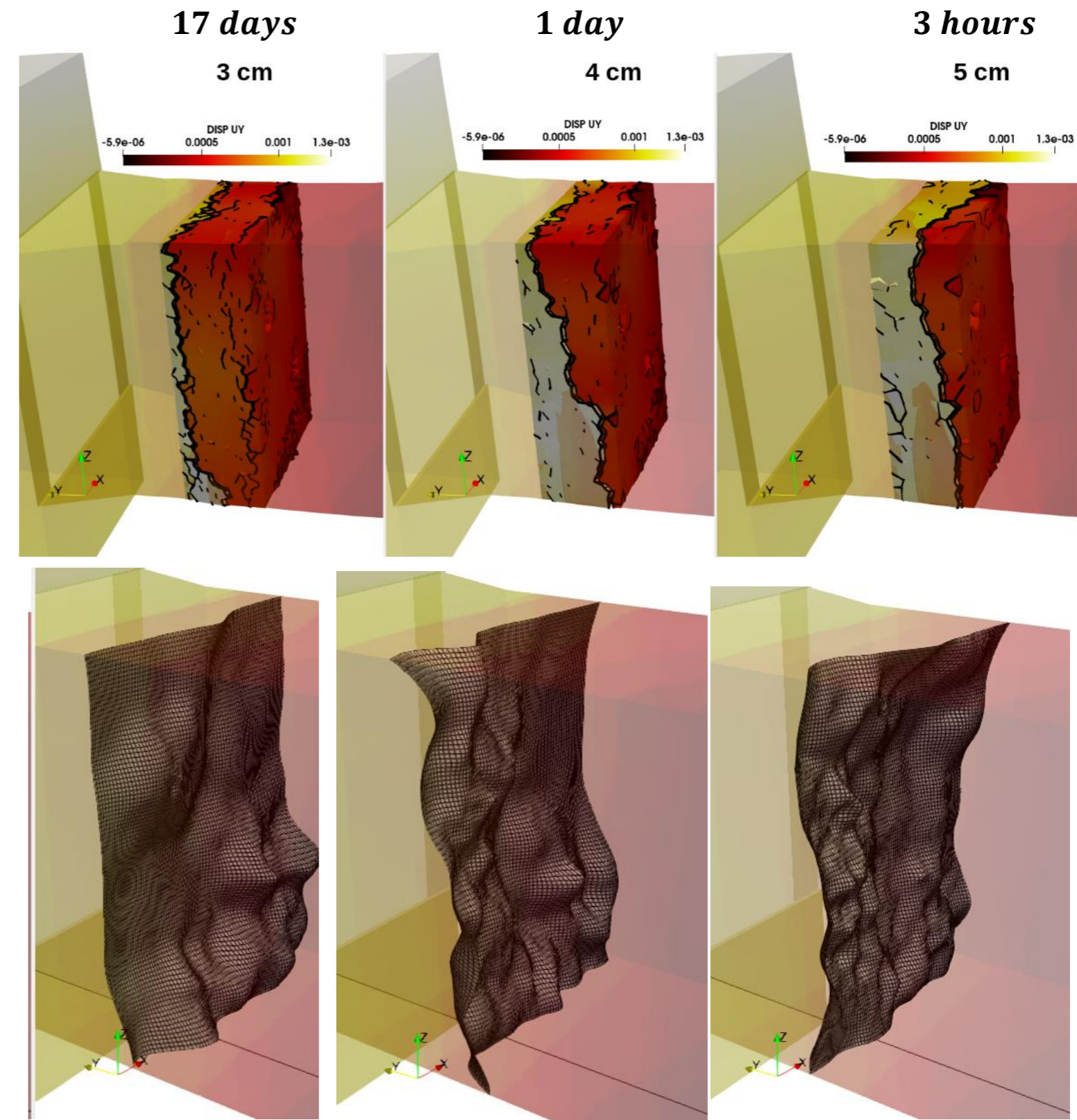
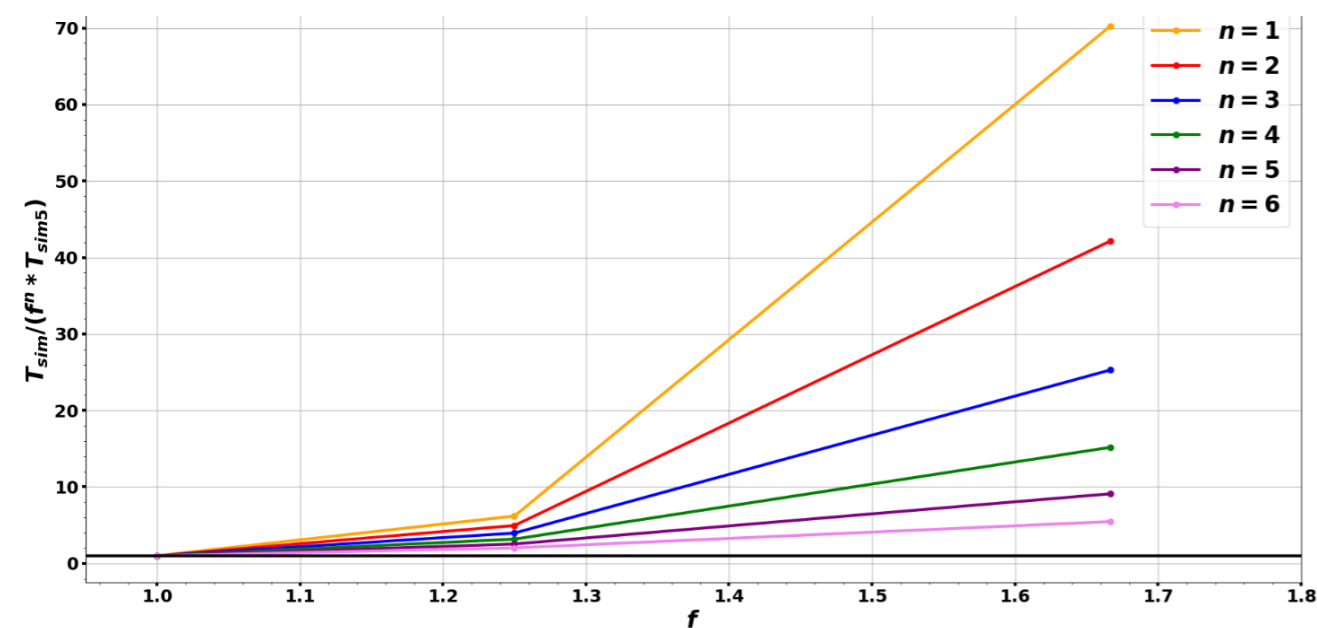
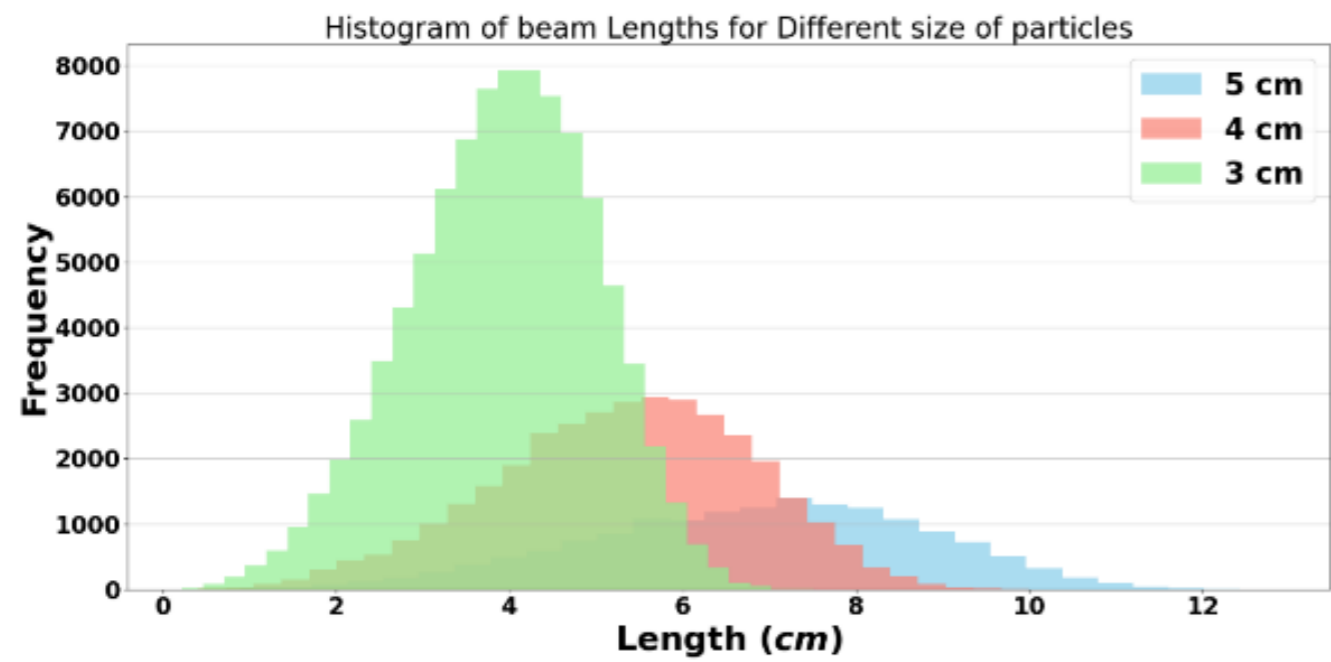
DEAP mesh & condition limits



DEAP mesh size study

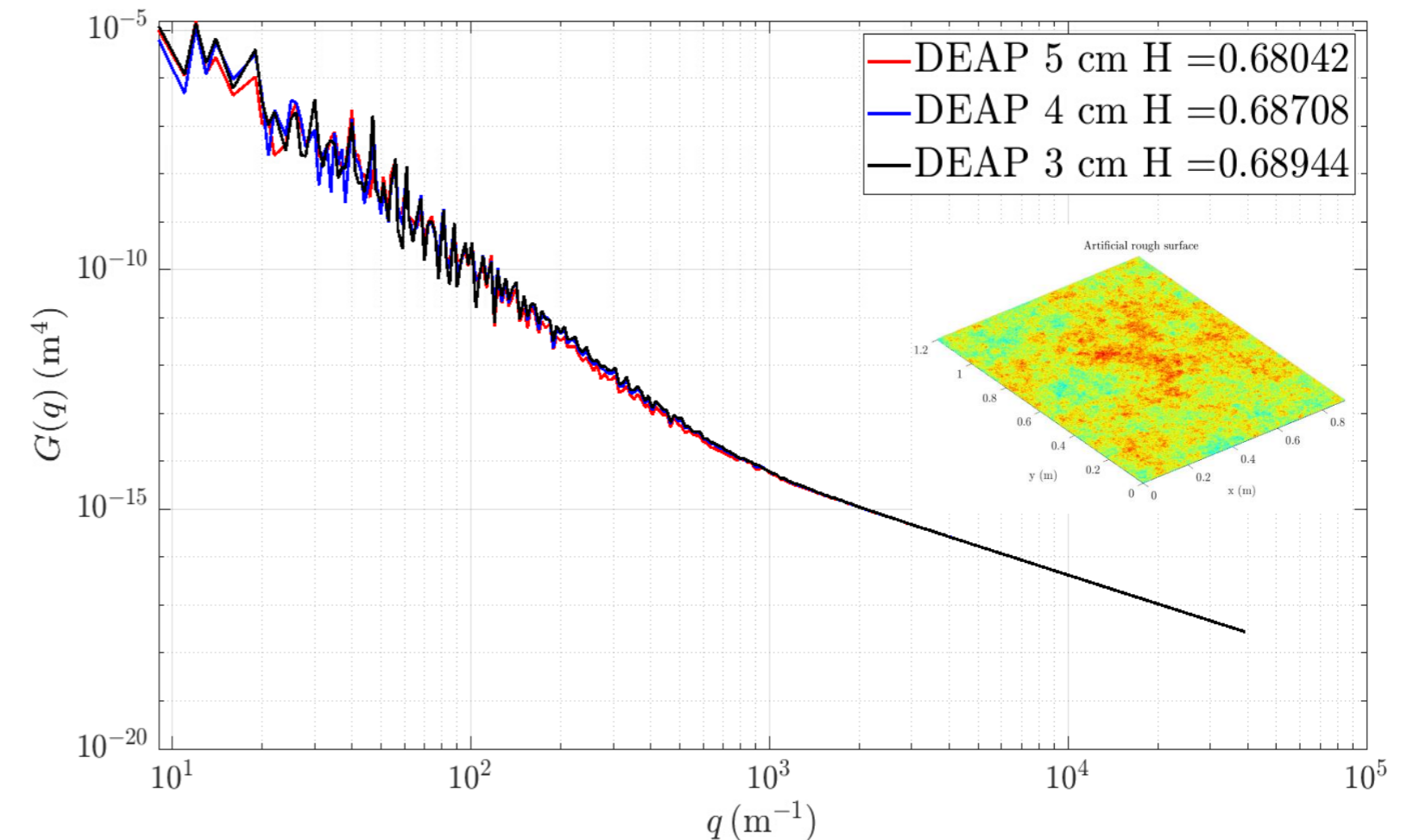
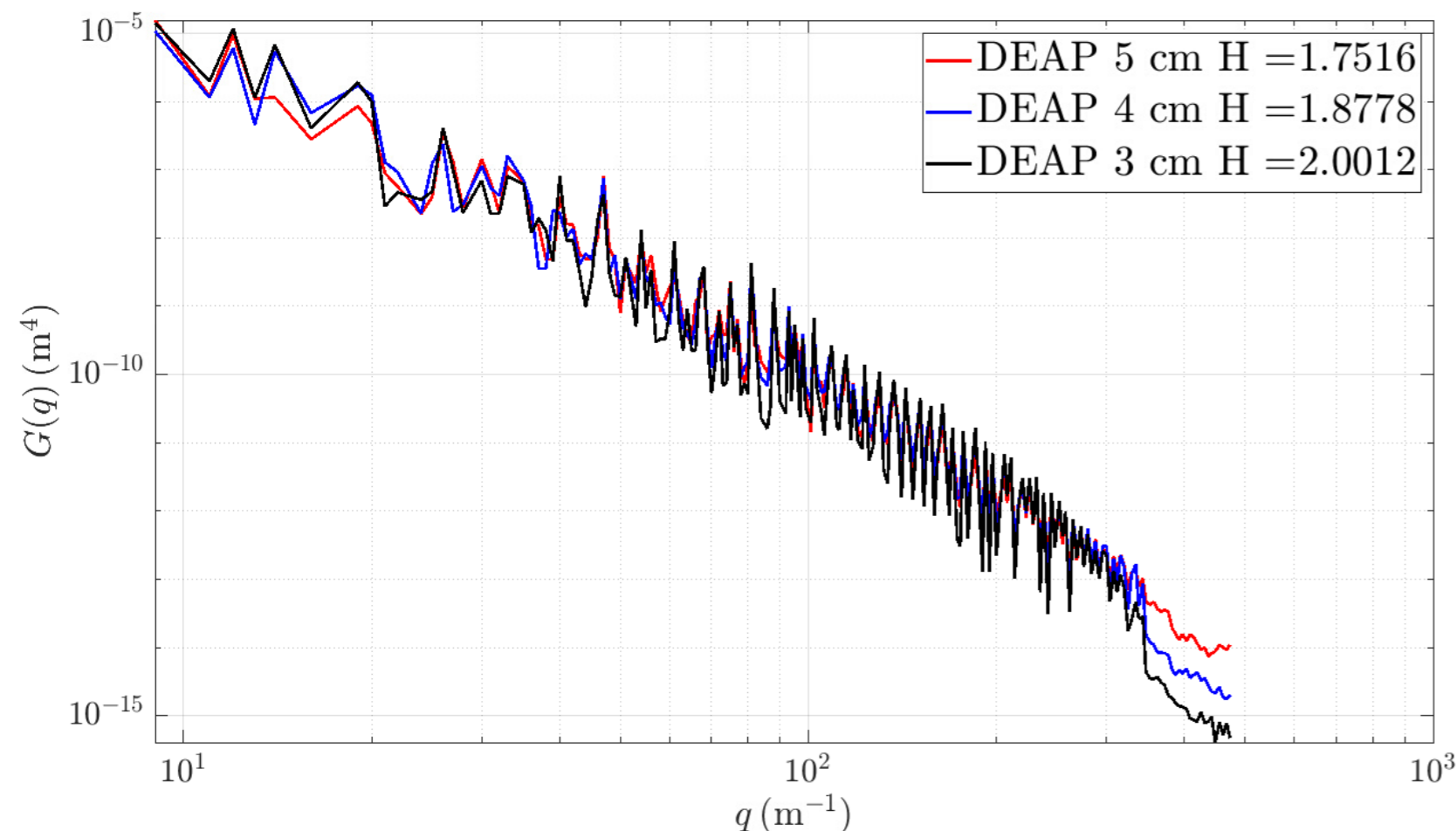
❖ Reducing the mesh size of a factor of f will increase:

- The stiffness matrix with f^3 ;
 - The number of broken beams with f^2 .
- Time** $\propto f^5$



DEAP mesh size study

- ❖ To assess the representativity of the obtained numerical crack, Hurst exponent factor is used;
- ❖ Spectral analysis showed the lack of roughness, $H > 1$, in DEAP simulations ($H \approx 0.8$ for real concrete cracks).
- ❖ Roughness can be included either:
 - explicitly generating of random noise in the crack surface on very small scale (High cost);
 - implicitly by introducing a roughness constant in CFD simulations, e.g., sand grain roughness on the wall.
- ❖ The choice of 5 cm is optimal;



$$G(q) = \Lambda q^{-2H-D}$$

q : wave vector (m^{-1}) $G(q)$: Power spectral density function (m^4)
 Λ : Scaling factor
 H : The Hurst exponent The fractal dimension

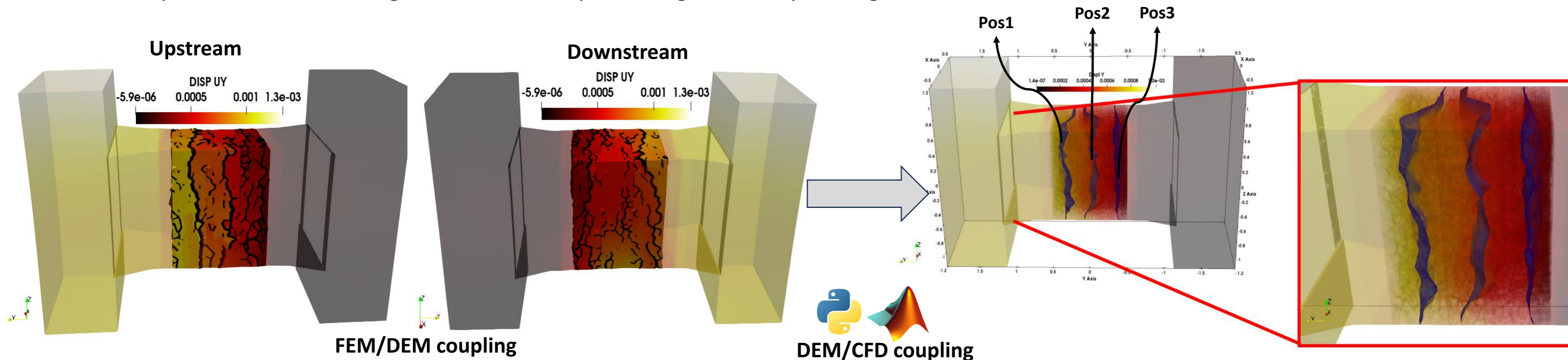
$0 < H < 1$ When:

- $H \approx 0$ the surfaces are the roughest;
- $H \approx 1$ the surfaces are relatively smooth.

[C Y Poon et al., 1992]

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- ❖ The choice of 5 cm is optimal;
- ❖ The complete FEM/DEM using 5 cm showed a promising results by having 3 different macro cracks.

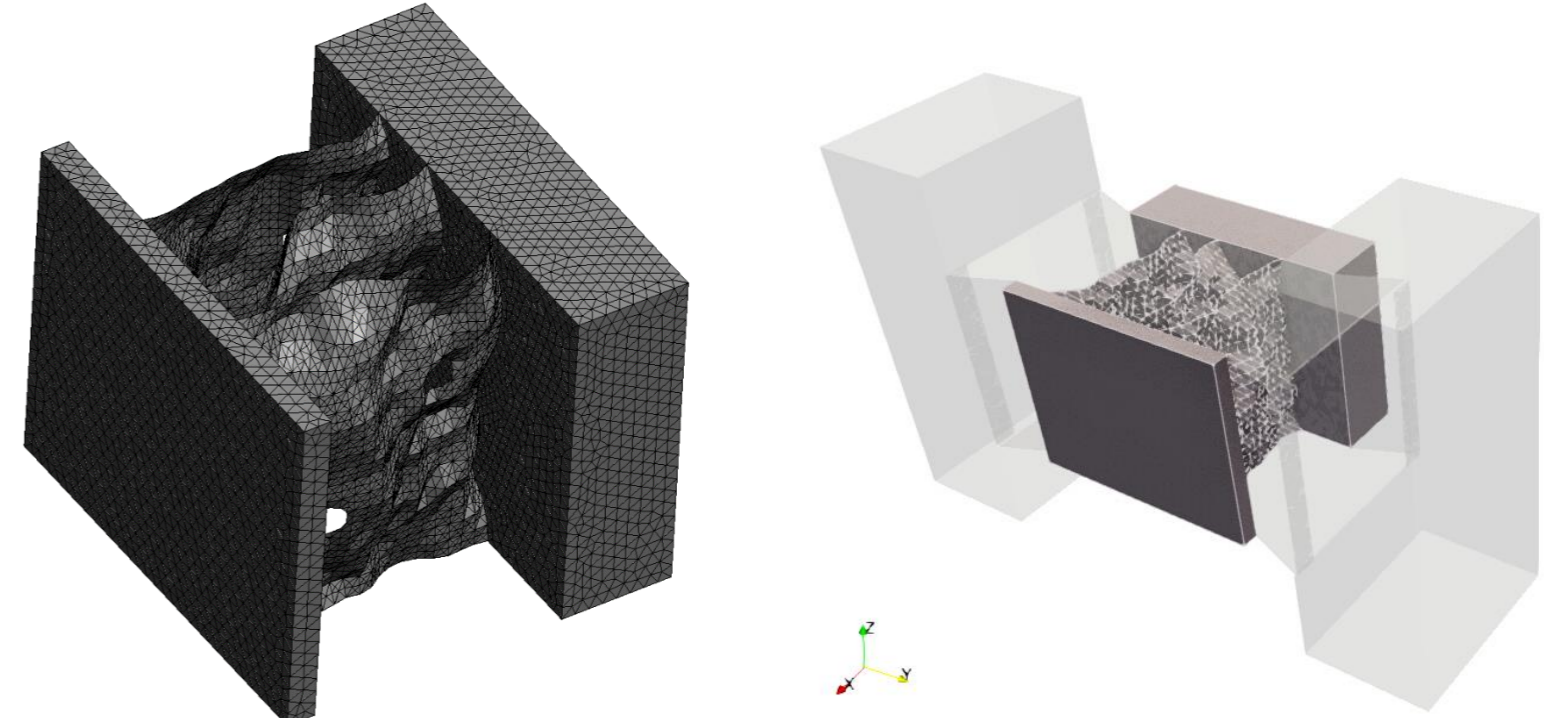
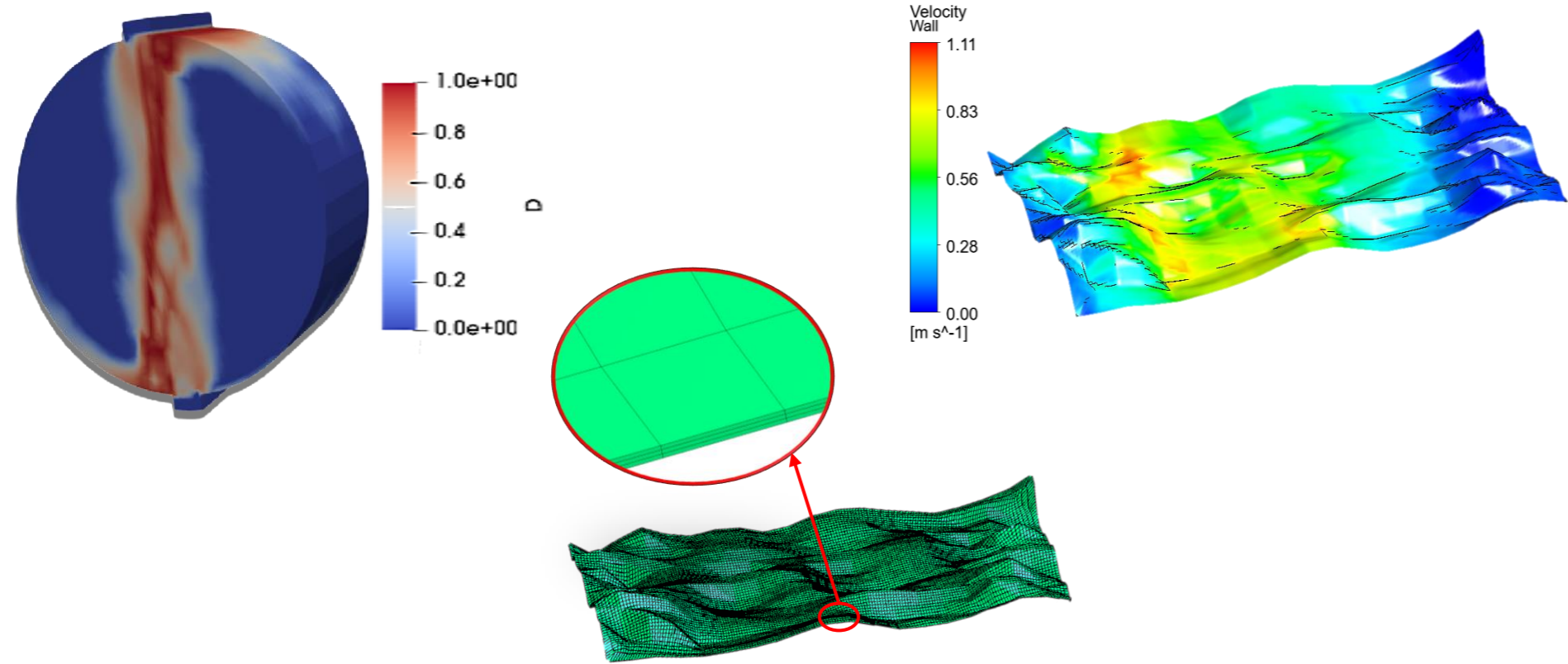


Conclusions

Perspectives

- Developing a tool capable of converting a stress strain state to a real crack structure compatible with CFD simulations;
- The ability of the tool to capture tortuosity of concrete cracks;
- The level roughness needed to be introduced is important to find a compromise between roughness description and CFD computational costs.

- Validate the CFD simulations for the concrete crack geometries (Brazilian test and COBRA program);
- Perform statistical study to take into account randomness properties of concrete.



Thank you

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