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Polysilicon MEMS sensors: sensitivity to sub-micron imperfections

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Engineering motivations

- Polycrystalline silicon microstructures

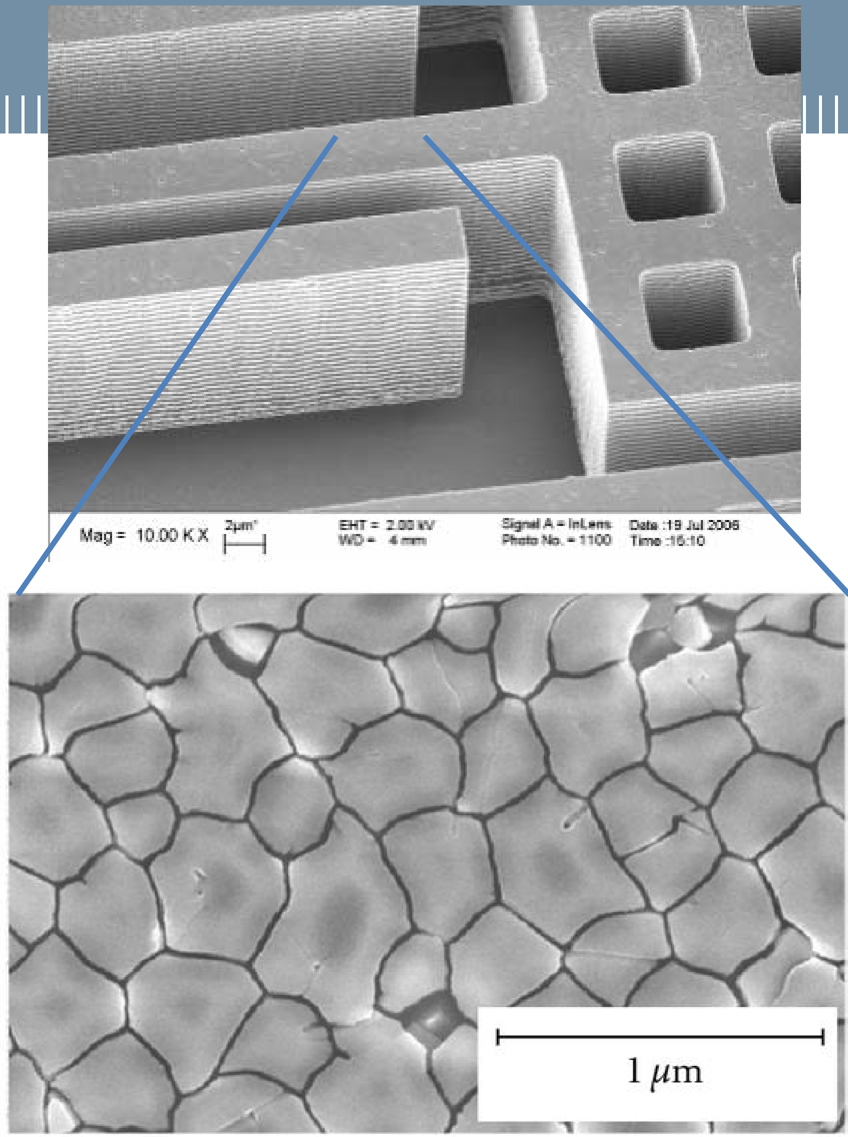
  ↓
- $d_{grain} \approx d_{structure}$

  scattering in the elastic properties

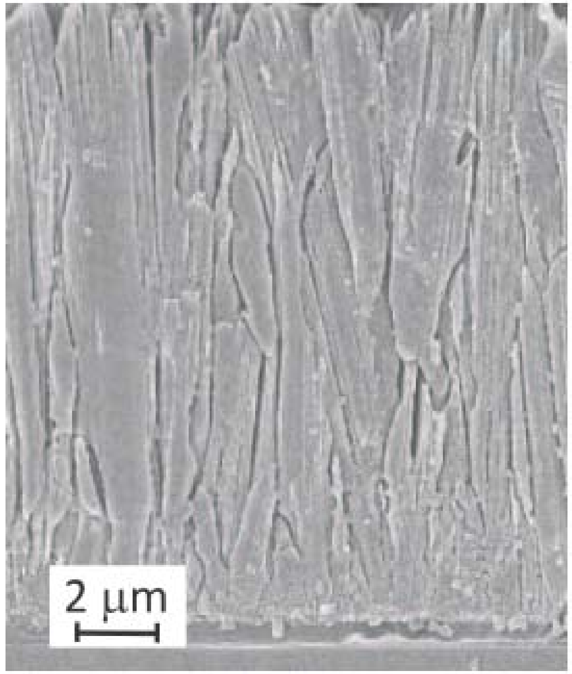
  ↓
- offset in operating devices

  ↓
- electronics compensation, causing performance reduction

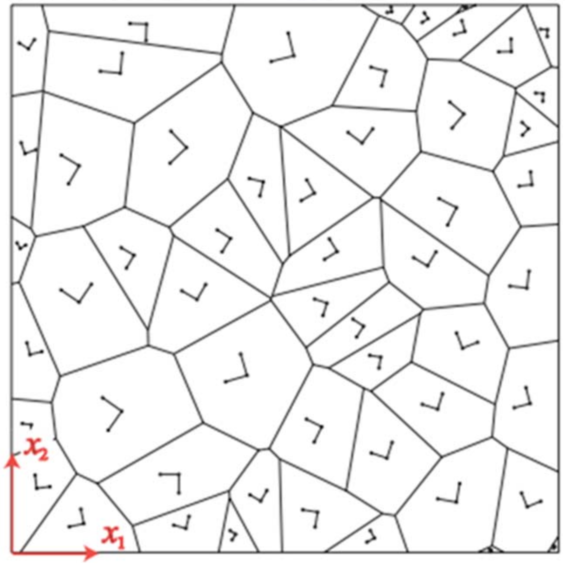
  ↓
- investigation on elastic behavior



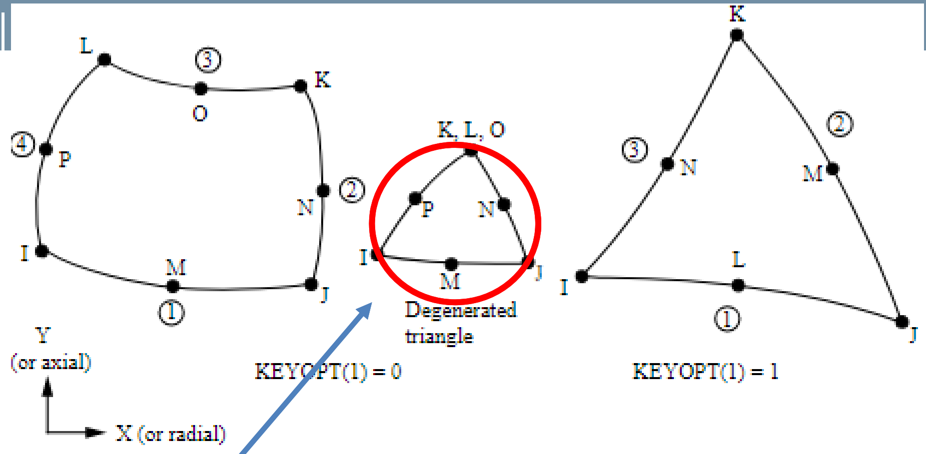
Suspension spring stiffness: finite element simulations



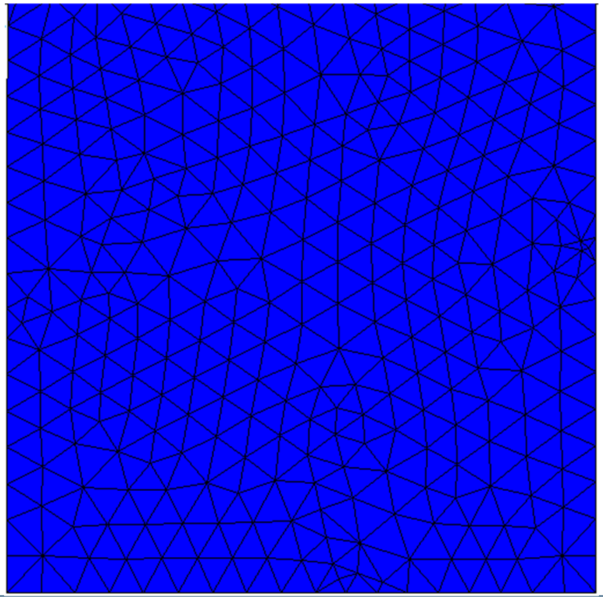
- Two-dimensional problem
- Si grains with their own lattice orientation
- Voronoi tessellation of the domain, Boolean operations, poly-Si structure (1 μm grain diameter)



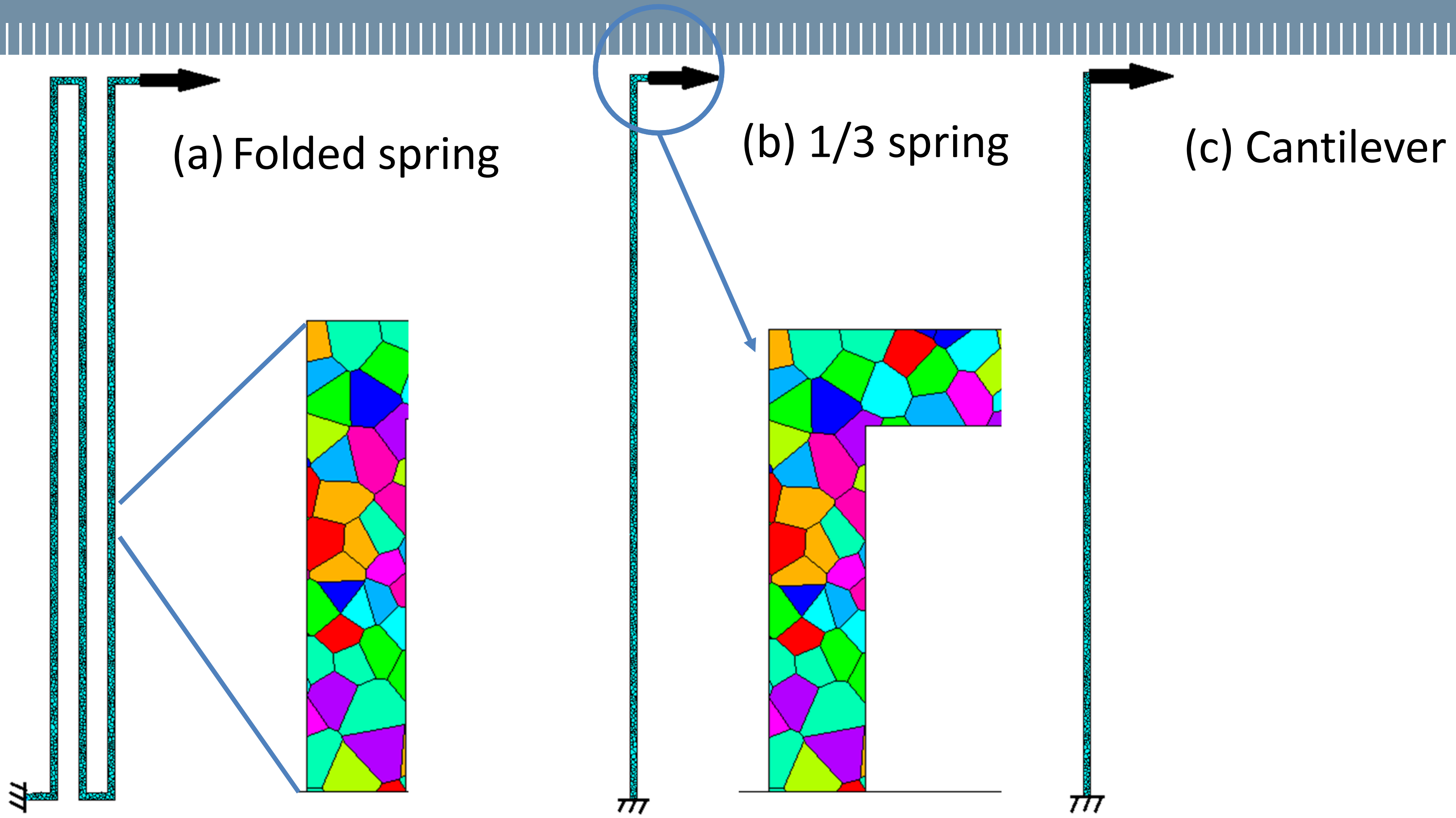
Suspension spring stiffness: finite element simulations



- Two-dimensional problem
- Si grains with their own lattice orientation
- Voronoi tessellation of the domain, Boolean operations, poly-Si structure (1 µm grain diameter)
- Mesh elements size 125 nm

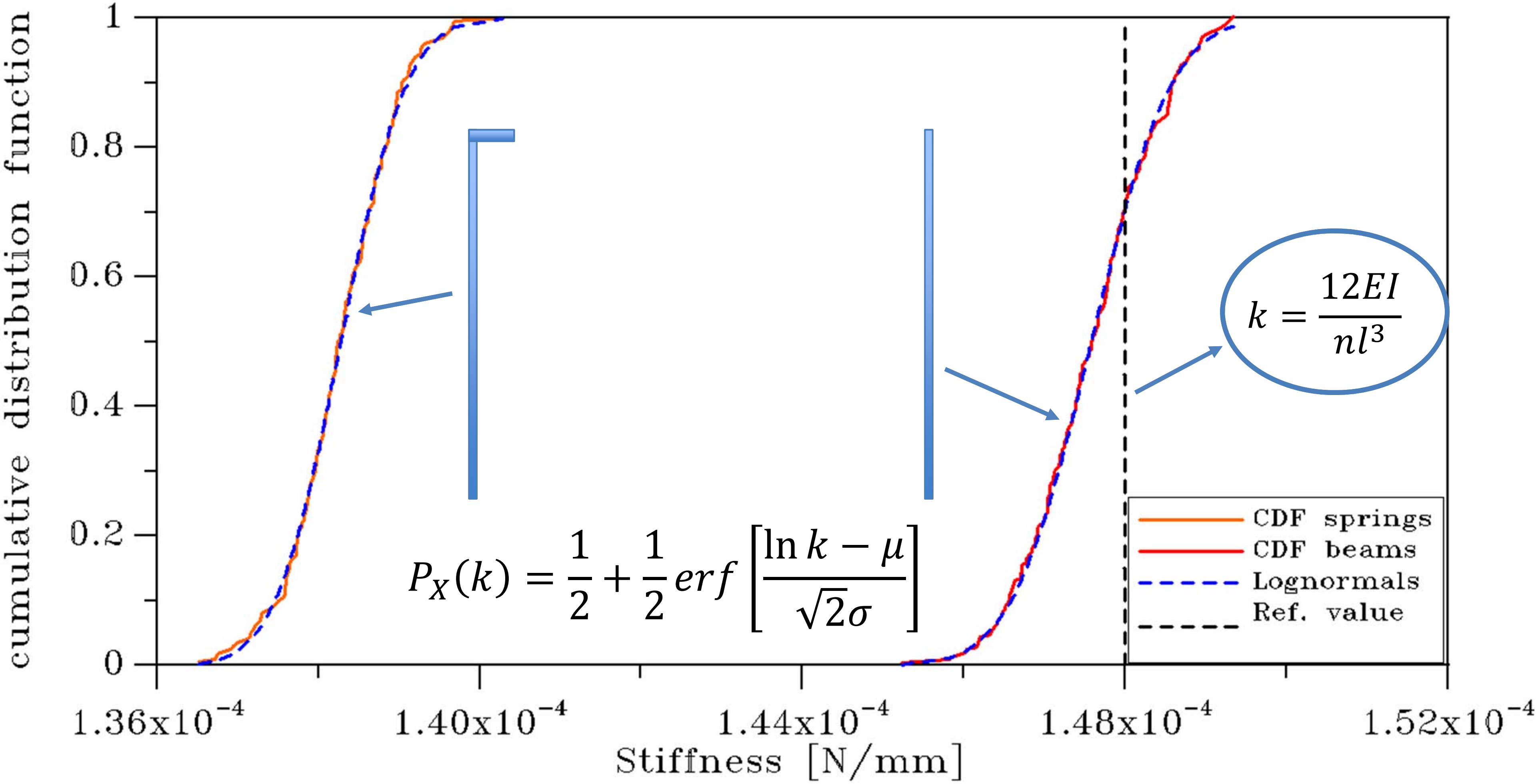


Spring geometries analyzed (Monte Carlo simulations)



Dimensions: length of 200 µm or 300 µm; width of 2 µm or 3 µm.

Monte Carlo results:
cumulative probability distributions for spring stiffness

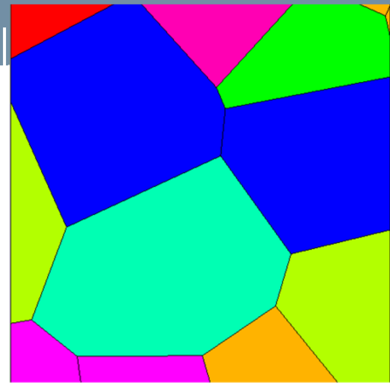


$$P_X(k) = \frac{1}{2} + \frac{1}{2} erf\left[\frac{\ln k - \mu}{\sqrt{2}\sigma}\right]$$

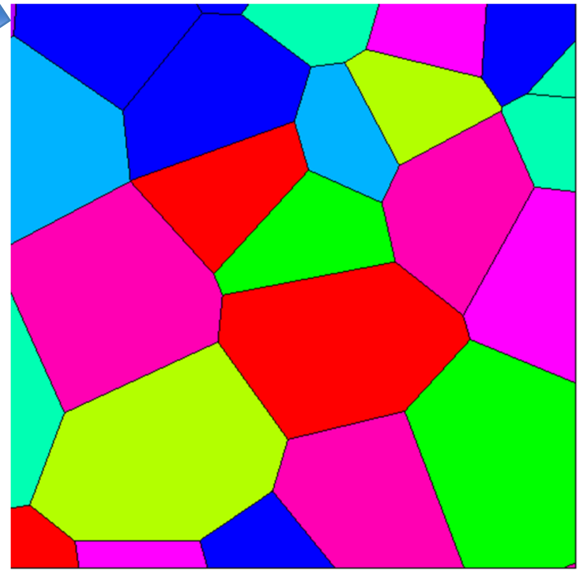
$$k = \frac{12EI}{nl^3}$$

Homogenization procedure on Statistical Volume Elements (SVEs)

- N simulations on SVEs featuring random grain orientation and morphology

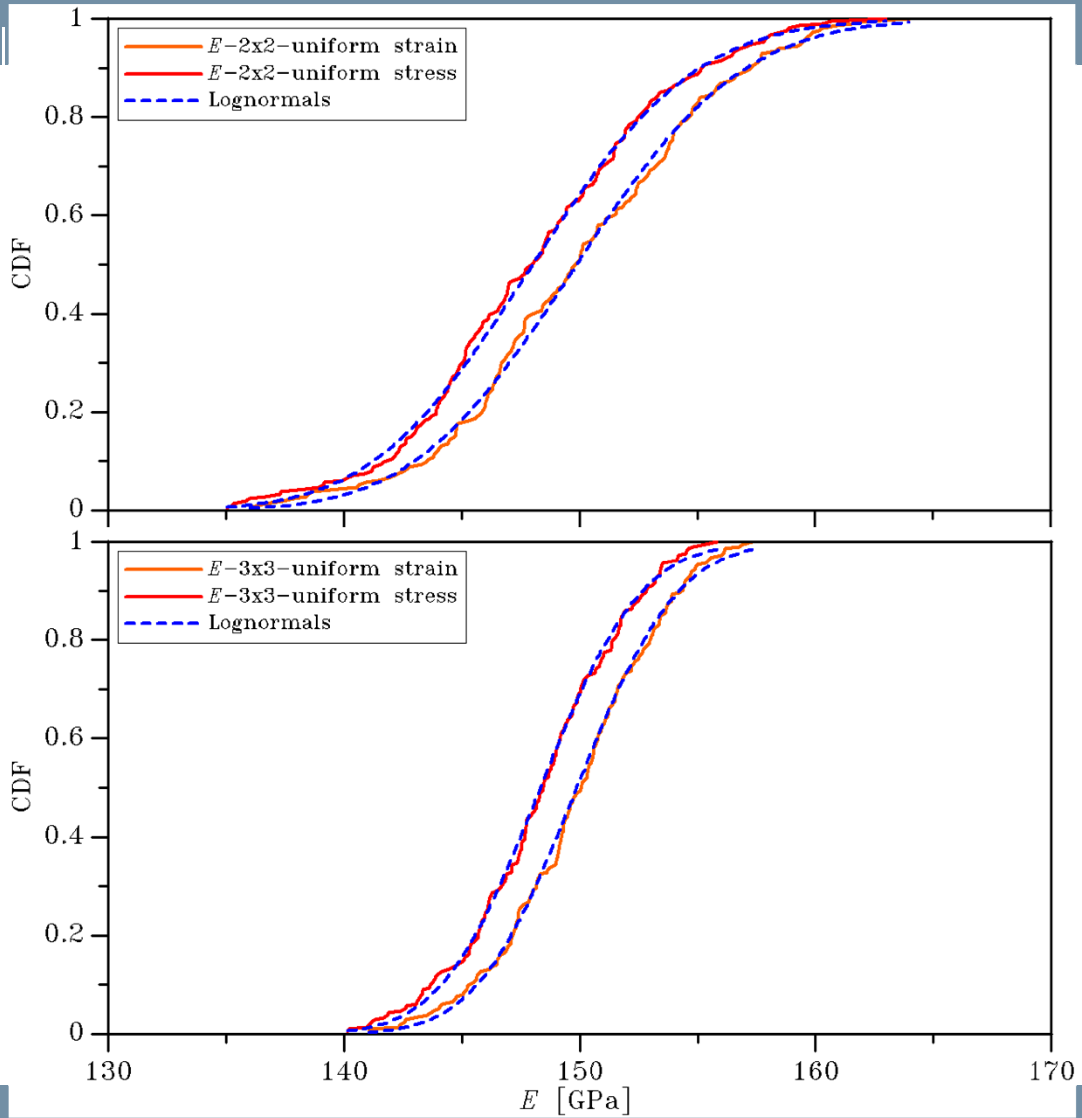


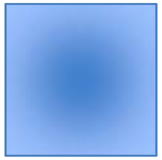
- Two SVE sizes: 2×2 μm and 3×3 μm



- Bilateral bounds on the elastic properties (E, G and ν) through either uniform stress or uniform strain boundary conditions

Homogenization results



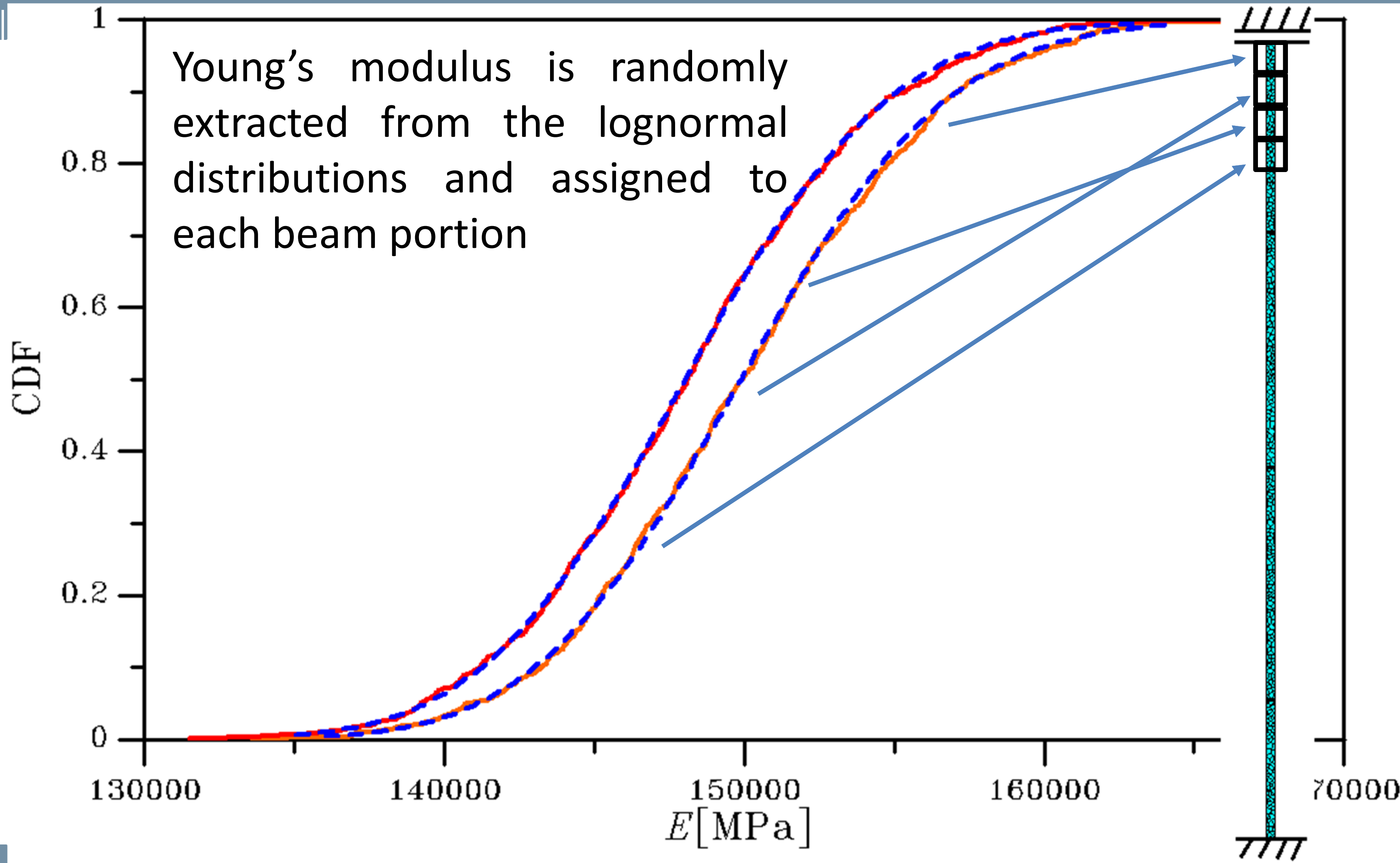


2×2 μm SVE

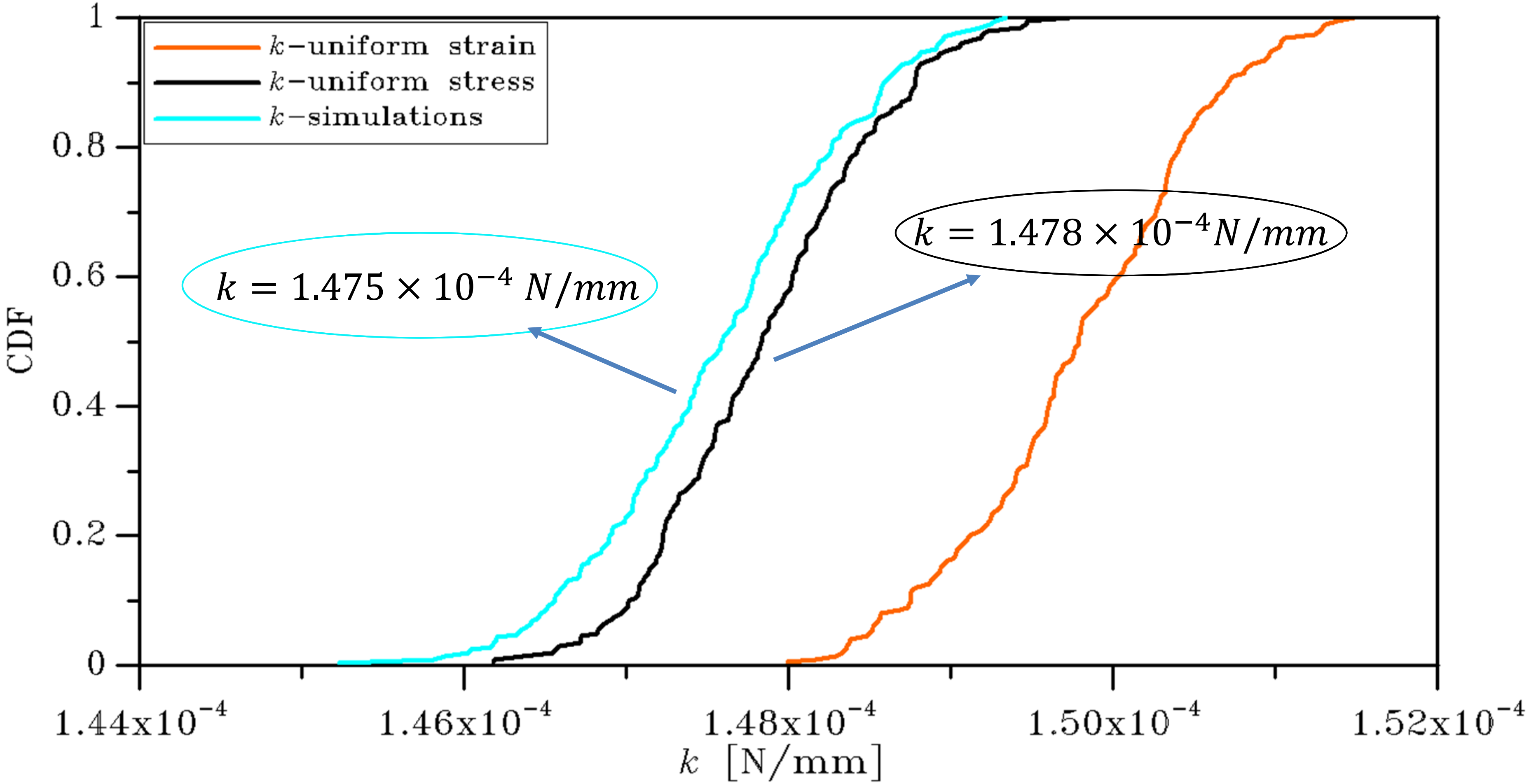
3×3 μm SVE

Analytical method to estimate the spring stiffness on the basis of the results at the SVE level

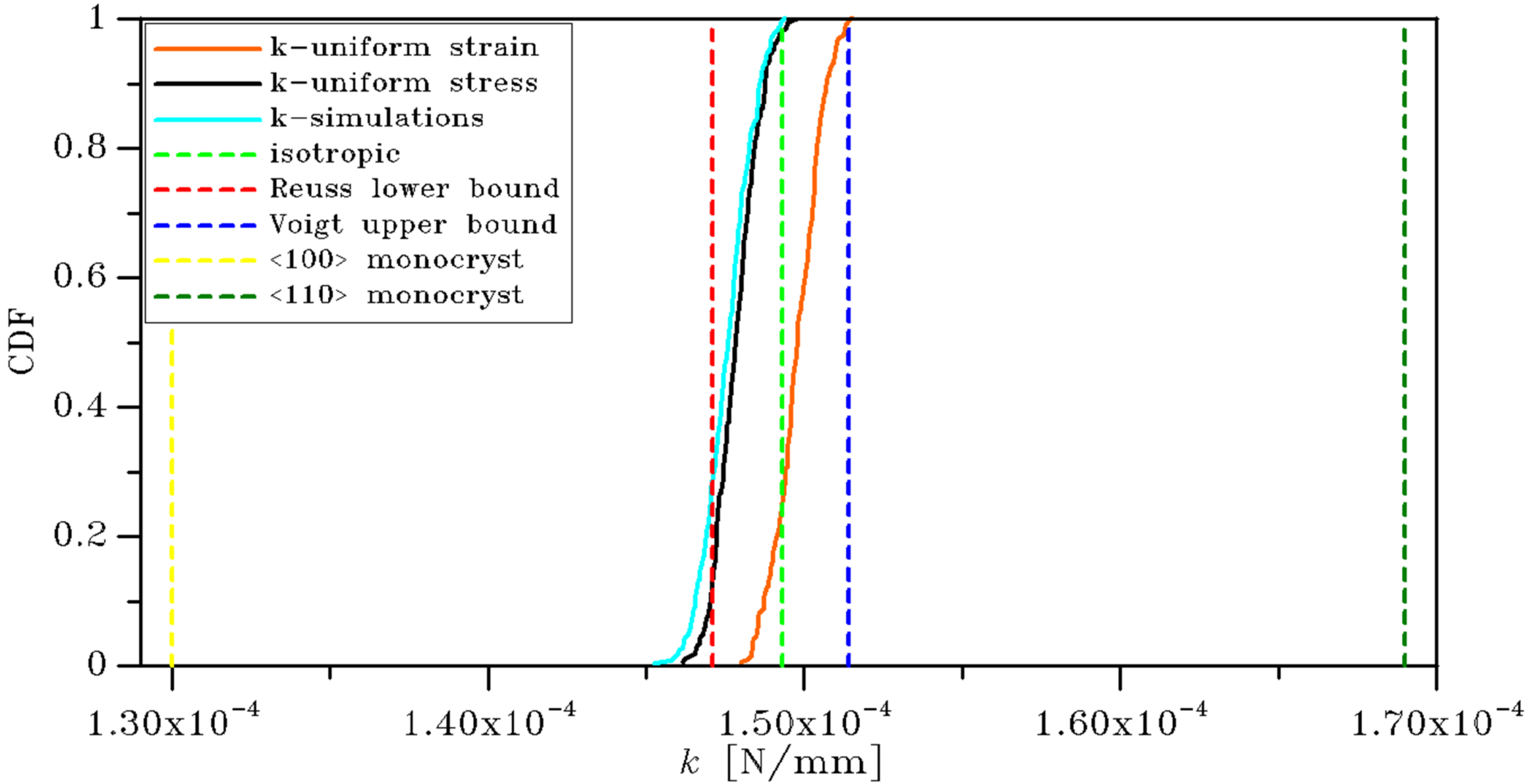
Young's modulus is randomly extracted from the lognormal distributions and assigned to each beam portion



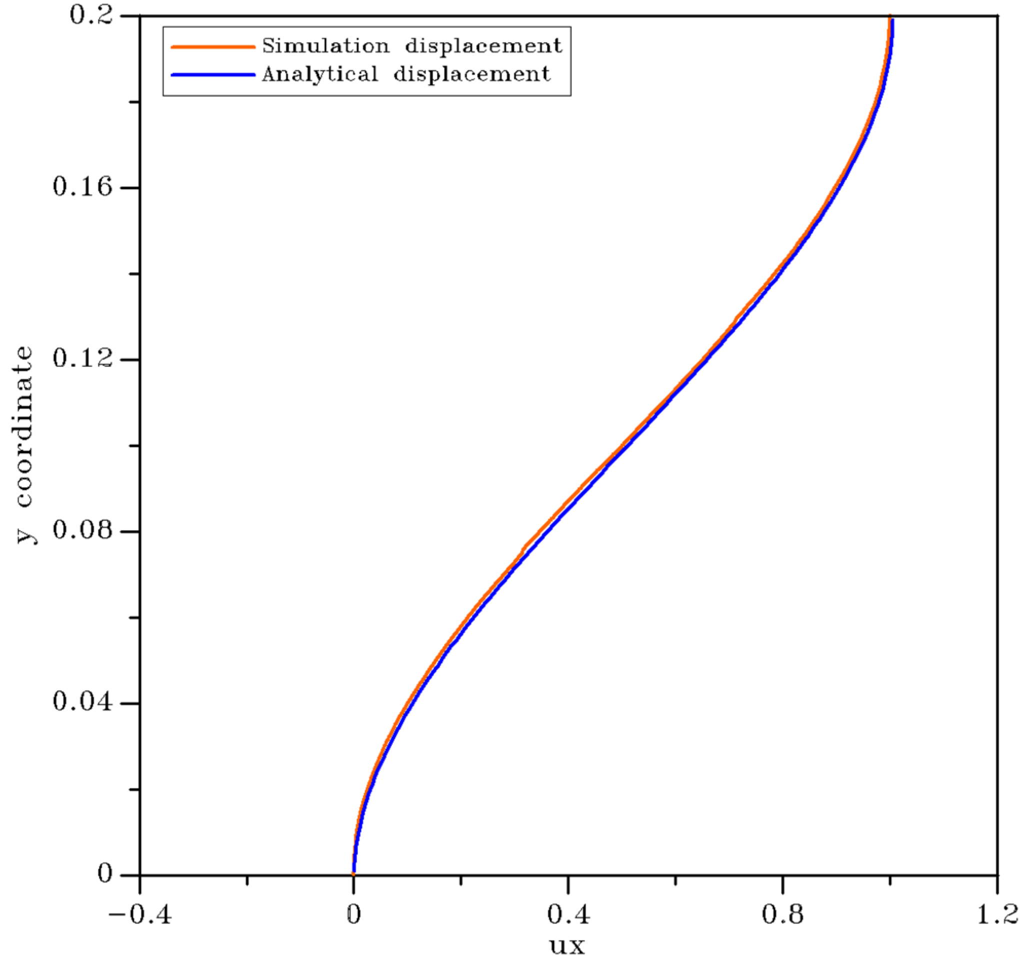
Comparison between FE and analytical results



Results check:
1\ comparison with bounds and representative solutions



Results check:
2\ comparison between the estimated deformation modes



Stochastic offset estimation

Different stiffness of springs plus residual stresses can lead to an offset of the seismic mass under rest conditions.

Offset (u) and resultant of the residual stresses (F) are linked through:

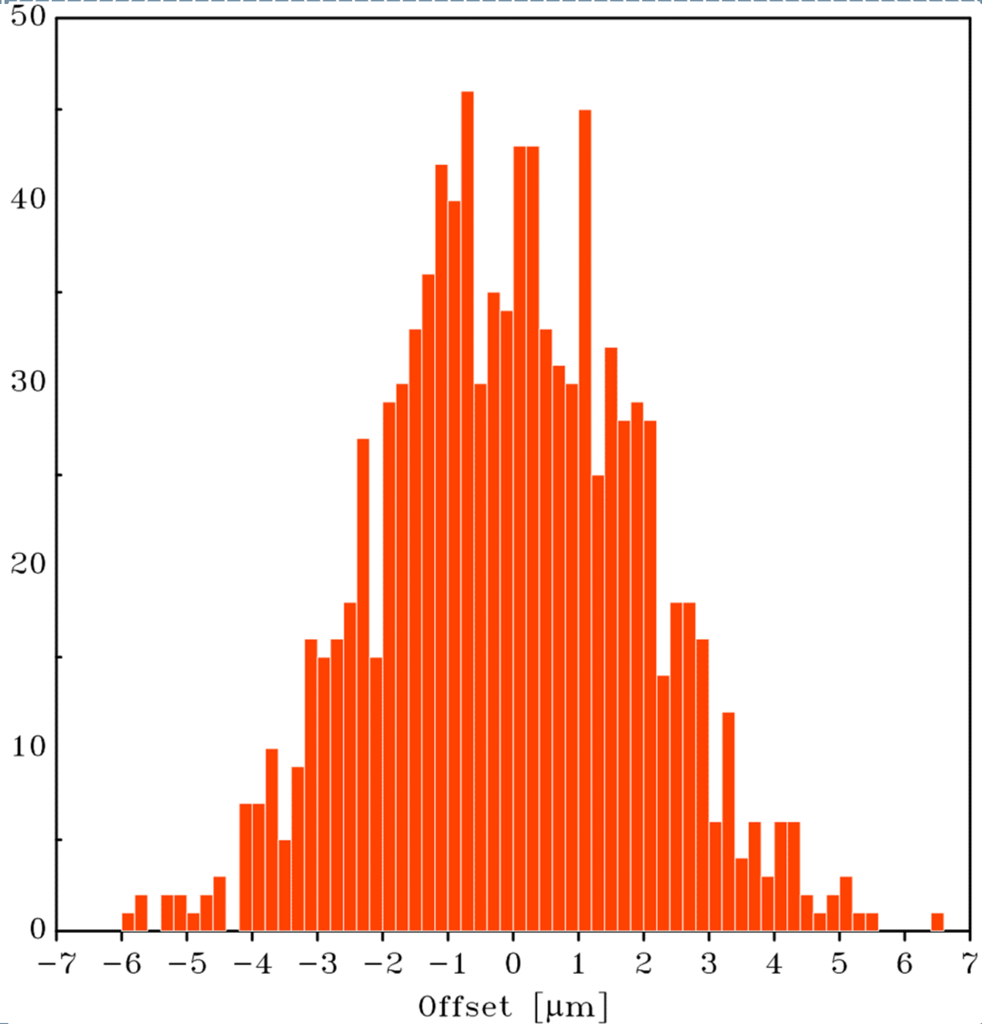
$$u = \frac{k_1 - k_2}{2k_1 k_2} F$$

where k_1 and k_2 are the two stiffness values.

Offset estimation

- Random value drawn from the stiffness probability distribution
- Random value drawn from the residual stresses distribution (assumed as a normal one with mean 10 MPa and standard deviation 1.67 MPa)

Offset estimation



Conclusions

- stiffness of polycrystalline silicon springs investigated through FE analyses.
- homogenization on SVE elastic properties to assess the statistical distribution due to the random microstructure.
- analytical method based on beam bending fed by the statistical distribution devised to compute the stiffness of polysilicon suspension springs.
- method applied for offset estimation in statically indeterminate structures.
- Future developments: comparison with experimental data; deeper investigation (and estimation) of residual stresses; accounting for the effects of overetch defects.