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Structural-genome-driven method for thin-walled composite structures

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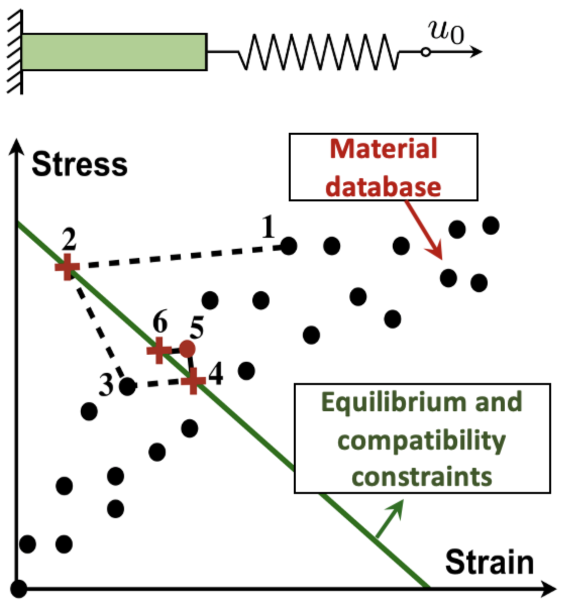
Abstract

This work aims to propose a data-driven computing algorithm integrated with model reduction technique to conduct mechanical analysis of thin-walled composite structures. The basic idea of distance-minimizing data-driven computing method [1] lies in directly employing the stress and strain data to drive the mechanical simulation. By introducing the Euler-Bernoulli beam or Kirchhoff-Love plate theory into data-driven computing, the reduced model is adopted by the proposed approach, namely structural-genome-driven (SGD) computing. The number of integration points will be greatly decreased, thereby enhancing the computational efficiency. Moreover, data-driven multiscale method is applied to the structural analyses of thin-walled composite beam/plate, for which the macroscopic computational cost will be hugely saved since it is conducted by searching structural-genome data in a database constructed offline by multiscale finite element method.

Methodology and context

Data-driven computational mechanics (DDCM) [1]

Advantage: completely abandon constitutive models



Equilibrium constraint:

$$R = \sigma A - k(u_0 - \varepsilon L) = 0$$

Distance penalty function:

$$F = \frac{(\sigma - \sigma^*)^2}{2\alpha} + \frac{\alpha(\varepsilon - \varepsilon^*)^2}{2}$$

Objective functional:

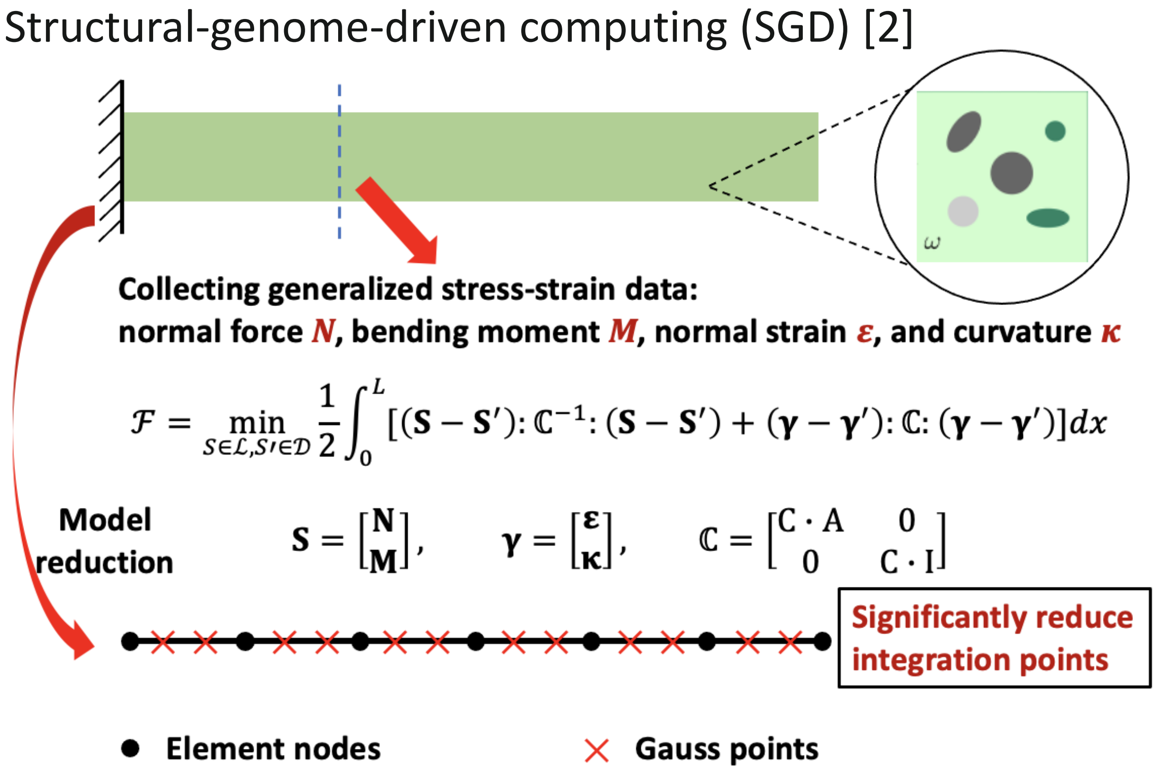
$$\delta(F - \lambda R) = 0$$

Iteration formulas:

$$\sigma^{(i+1)} - \sigma^{*(i)} = \frac{\alpha^2 A}{kL}\left(\varepsilon^{(i+1)} - \varepsilon^{*(i)}\right)$$

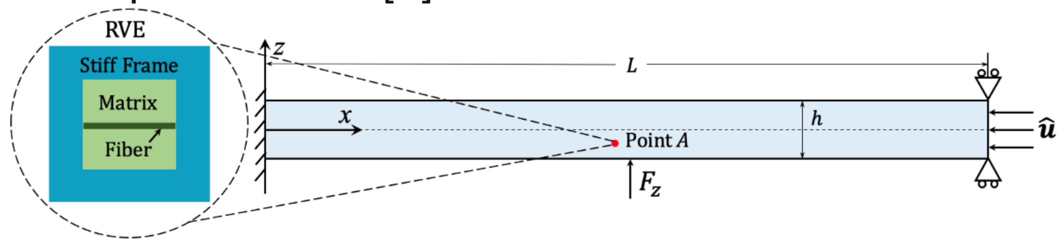
$$\sigma^{(i+1)} A + kL\varepsilon^{(i+1)} = ku_0$$

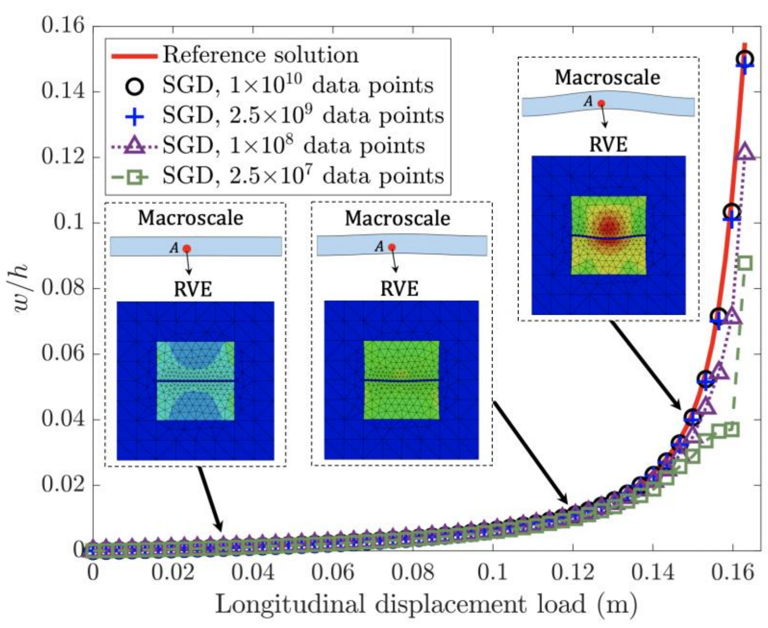
Structural-genome-driven computing (SGD) [2]



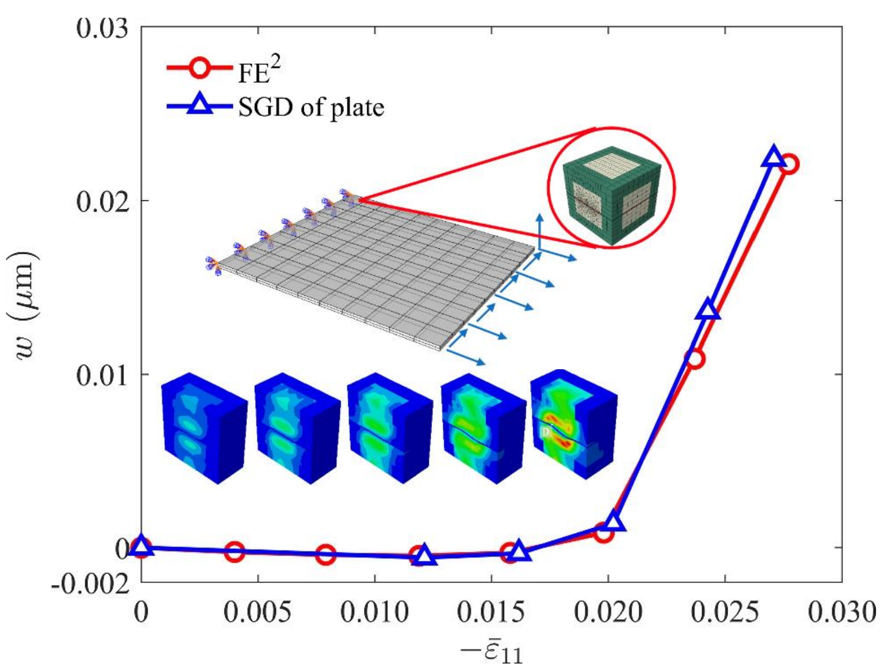
Results

Global-local-coupling instability analysis of composite beam [3]





Composite plate under combined loads [4]



Conclusion and perspectives

The results of SGD computing are in good agreement with those obtained from classical FEM or multiscale finite element method. On the one hand, the proposed algorithm permits to efficiently predict the strong nonlinear macrostructural mechanical response for composite beam when both the macro-level instability and micro-level fibre buckling occur. On the other hand, for the case of composite plate, even if the microstructure presents an obvious nonlinear buckling behavior, the SGD computing still performs well and is able to accurately track the instability curve. The influence of data density is also investigated in this work, showing that a satisfactory accuracy of data-driven computing will be achieved with higher-density database adopted.

References

[1] Kirchdoerfer T., Ortiz M., Data driven computational mechanics. ***Comput Methods Appl Mech Eng*** 304, 81-101 (2016).
[2] Yang J., Xu R., et al. Structural-genome-driven computing for composite structures. ***Compos Struct*** 215, 446-453 (2019).
[3] Bai X., Yang J., et al. A data-driven approach for instability analysis of thin composite structures. ***Comput Struct*** 273, 106898 (2022).
[4] Yan W., Huang W., et al. Data-driven multiscale method for composite plates. ***Comput Mech*** 70, 1025-1040 (2022).

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