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Unified functional based data-model-coupling computing for composite structures

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Abstract

The coupling of model-free data-driven computing and model-driven computing has been proposed recently, in which the model-driven computing refers to the constitutive model-based simulations. Specifically, the data-driven computing is applied for the local region of the structure to avoid empirical material modeling, while the constitutive model-driven computing based on traditional FEM is employed for the rest regions of the structure to improve the numerical efficiency. This article aims to further prove that data-driven and model-driven computing can share the same distance-based functional. Moreover, data-model-coupling computing based on extended FEM is applied for the analyses of crack propagation problem. A concrete-rock composite beam with initial interface crack is considered to demonstrate the effectiveness of the proposed coupling strategy for the analyses of composite structures.

Methodology

The formulations for data-model-coupling computing is expressed as the following:

$$\Pi = \sum_{e\in S_1} w_e \mathscr{F}_e(z_e, z_e^*) - \eta^{\mathrm{T}} \cdot \left(\sum_{e\in S_1} w_e \mathbf{B}_e : \sigma_e + \sum_{e\in S_2} w_e \mathbf{B}_e : \mathbb{D}_e : \mathbf{B}_e \cdot u - f \right)$$

Taking all possible variations of above equation:

$$\sum_{e\in S_1} w_e \mathbf{B}_e : \mathbb{C}_e : \mathbf{B}_e \cdot \boldsymbol{u} - \sum_{e\in S_2} w_e \mathbf{B}_e : \mathbb{D}_e : \mathbf{B}_e \cdot \boldsymbol{\eta} = \sum_{e\in S_1} w_e \mathbf{B}_e : \mathbb{C}_e : \varepsilon_e^*$$

$$\sum_{e\in S_2} w_e \mathbf{B}_e : \mathbb{D}_e : \mathbf{B}_e \cdot \boldsymbol{u} + \sum_{e\in S_1} w_e \mathbf{B}_e : \mathbb{C}_e : \mathbf{B}_e \cdot \boldsymbol{\eta} = \boldsymbol{f} - \sum_{e\in S_1} w_e \mathbf{B}_e : \sigma_e^*$$

The enriched displacement approximation of the whole domain can be expressed as:

$$\mathbf{u}(\boldsymbol{x}) = \sum_{J\in\mathcal{N}} \boldsymbol{N}_J(\boldsymbol{x})\boldsymbol{u}_J + \sum_{J\in\mathcal{N}_C} \boldsymbol{N}_J(\boldsymbol{x}) H(\boldsymbol{x}) \boldsymbol{a}_J + \sum_{J\in\mathcal{N}_K} \boldsymbol{N}_J(\boldsymbol{x}) \sum_{\alpha=1}^{m} \boldsymbol{\Phi}_\alpha(\boldsymbol{x}) \boldsymbol{b}_J^\alpha$$

$$[\boldsymbol{\Phi}_\alpha, \alpha = 1-4] = \left\{ \sqrt{r}\sin\frac{\theta}{2}, \sqrt{r}\cos\frac{\theta}{2}, \sqrt{r}\sin\frac{\theta}{2}\sin\theta, \sqrt{r}\cos\frac{\theta}{2}\sin\theta \right\}$$

The maximum tangential stress criterion is employed to determine the propagation direction

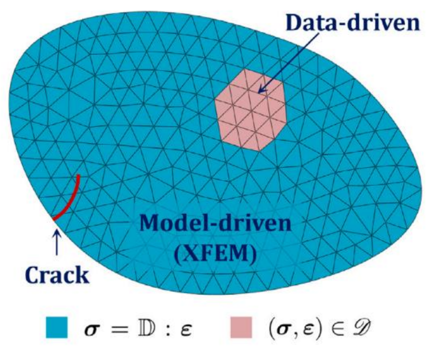
$$\left. \frac{\partial \sigma_{\theta\theta}(\mathbf{K}, \theta)}{\partial \theta} \right|_{\theta=\theta_{\max}} = 0$$

Conclusion and perspectives

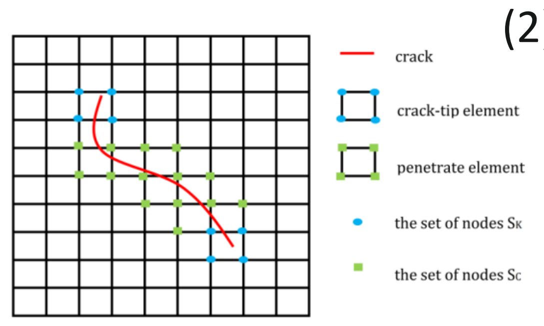
In the present work, data-model-coupling computing is proposed for the analyses of composite structures. The proposed data-model-coupling computing based on XFEM is validated via the application to the crack propagation analyses of a concrete-rock composite beam with an initial interface crack. In future work, it is of interest to extend the applications of the proposed data-model-coupling computing for heterogeneous materials and structures.

Context

The simulation of the crack propagation can be executed with an iteration process:



(1) Obtain the stress fields by using data-model-coupling computing, in which the data-driven iterations are performed;



(2) Determine the propagation direction and extend the crack with a user-defined length.

Results

	Proposed coupling model	Pure XFEM model	Relative error
K_1 (Mpa$\sqrt{\mathrm{m}}$)	0.1021	0.1	2.2%
K_2 (Mpa$\sqrt{\mathrm{m}}$)	−0.7667	−0.77	0.5%
G (J/m^2)	25.2	25.4	0.8%

Table 1 The stress intensity factors $\mathbf{K} = K_1 + iK_2$ and the energy release rate G obtained by the data-model-coupling computing and pure XFEM [1].

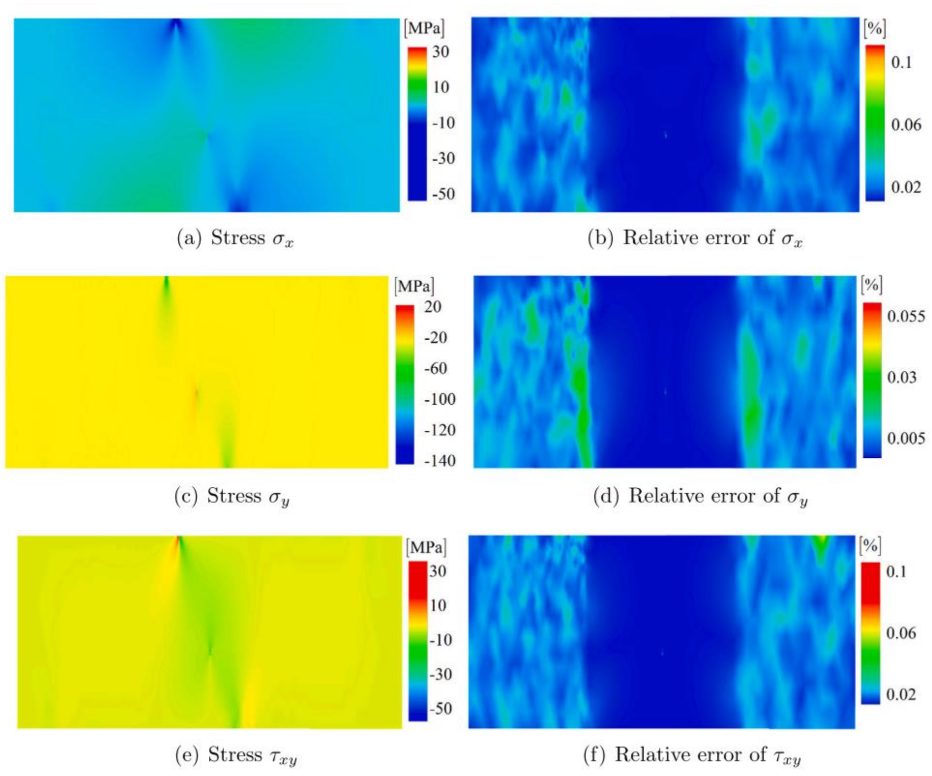


Fig. 1. Distributions of stress components via the proposed coupling model and their relative errors before the initial crack propagation [1].

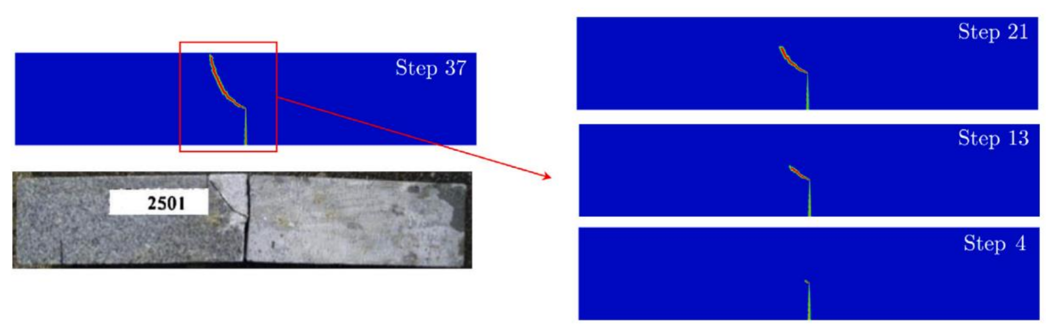


Fig. 2. Comparison of the crack propagation via the proposed coupling model and experiments [2].

References

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