Journal of Zhejiang University-SCIENCE A (Applied Physics & Engineering)

A deep energy method for functionally graded porous beams

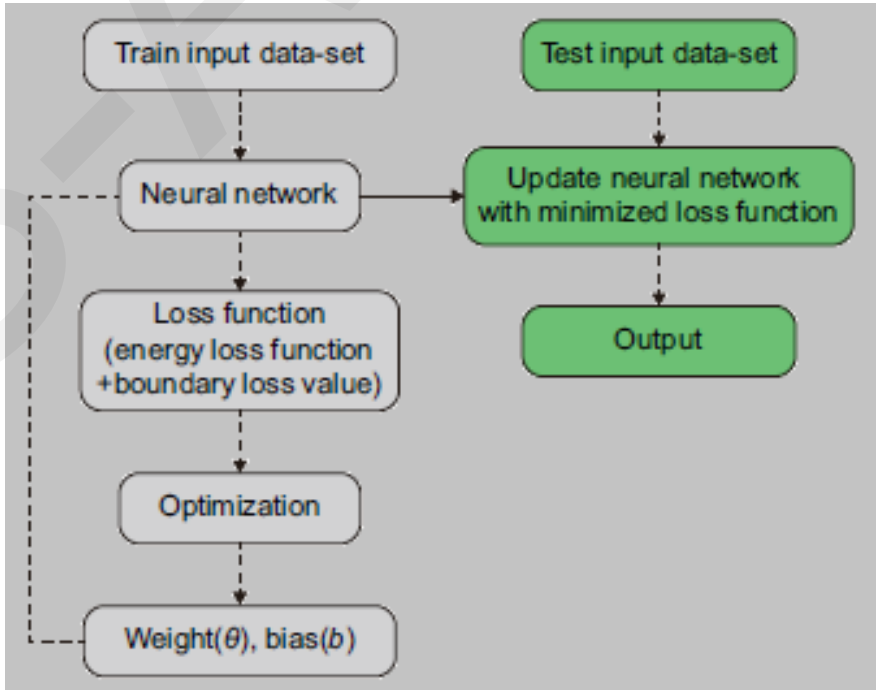
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Deep energy method Algorithm

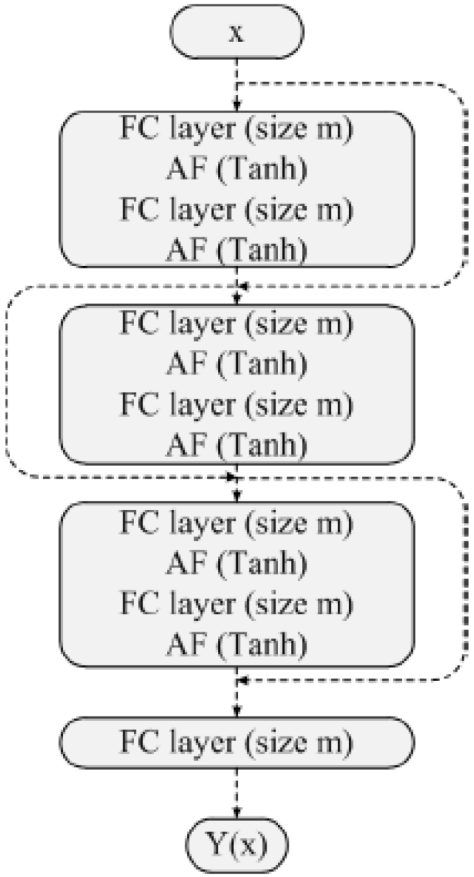
- Data of beam length
- multilayer perceptron (MLP) comprise an input layer, hidden layers, and an output
- a loss function, which is the potential energy (variational energy) of the system.
- variational energy as an objective function to optimize the neural network. objective function is minimized using the Adam optimizer.



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Neural network architecture

- **Input Data (includes some point between both boundary conditions)**
- **Batching three blocks**
  a. Two fully connected (FC) linear transformations
  b. two nonlinear activation functions
  c. Residual connection
- **A Fully connected Layer**
- **Out put Layer (includes deflection of beam in each point)**



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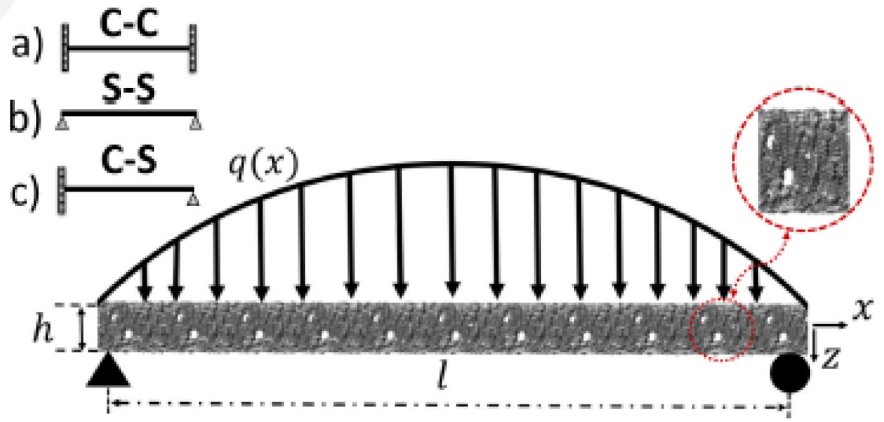
Energy method

The total potential energy (V) is the sum of strain energy (U) and the potential energy of the applied load (W):

$$V = U + W$$

$$U = \frac{1}{2}\int_v (\sigma_{xx}\varepsilon_{xx})dv$$

$$W = -\int_x q(x)w(x)dx,$$



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Loss function and optimization

DEM is based on minimizing the potential energy

$$V = \int_x F(u, w, \frac{du}{dx}, \frac{dw}{dx}, \frac{d^2w}{dx^2}; x)dx + h(Y_L, Y_0)$$

Using the rectangle rule to evaluate the integrals

$$V = \frac{1}{n}\sum_{j=1}^{n} F_j(\theta, b) + \frac{\beta}{n_b}\sum_{i=1}^{n_b}(h_i(\theta, b) - h_i(Y_L, Y_0))^2$$

We used the Adam optimizer, which is based on the stochastic gradient descent method and readily available in PyTorch.

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Results

The relative errors obtained from this network architecture and FC neural network are compared in the Table .

$\star$	$R_e \times 10^{-2}$		
Layers	Fully connected		Residual connected
6	4.228	$S-S$	4.222
	3.520	$C-C$	3.496
	1.490	$C-S$	1.479
8	3.382	$S-S$	2.533
	2.816	$C-C$	2.098
	1.192	$C-S$	0.887
10	3.044	$S-S$	1.520
	2.534	$C-C$	1.260
	1.073	$C-S$	0.532
12	2.739	$S-S$	0.912
	2.280	$C-C$	0.756
	0.966	$C-S$	0.319

The Figure compares the solution of DEM with the exact solution for and simply-simply boundary conditions.

