A SURROGATE MODEL BASED ON CLT FOR NONLINEAR STRESS ANALYSIS OF LAMINATED STRUCTURES

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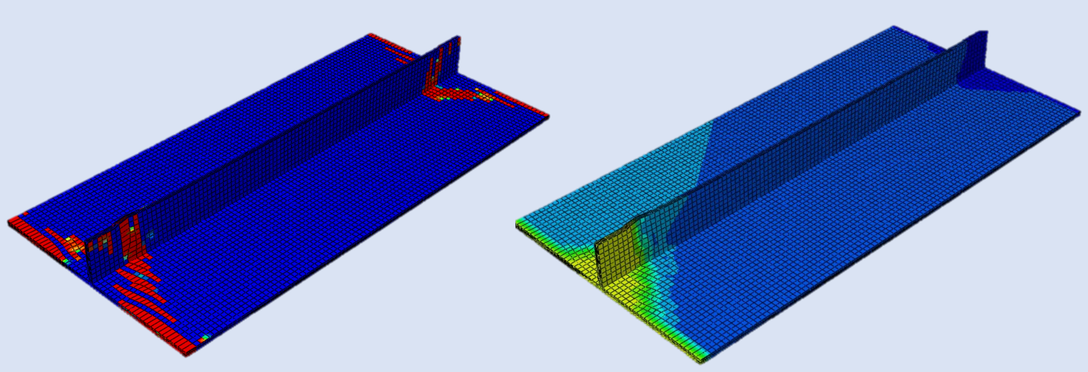
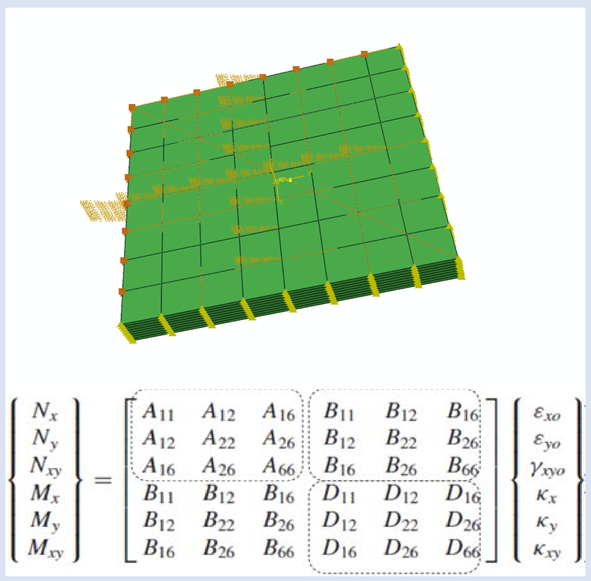
Background & Aims

- Laminated structures used in aviation industry
  - complex structural
  - out-plane loading conditions
- Analysis of strength and progressive damage
  - nonlinear behavior after damage initiation
  - High time cost

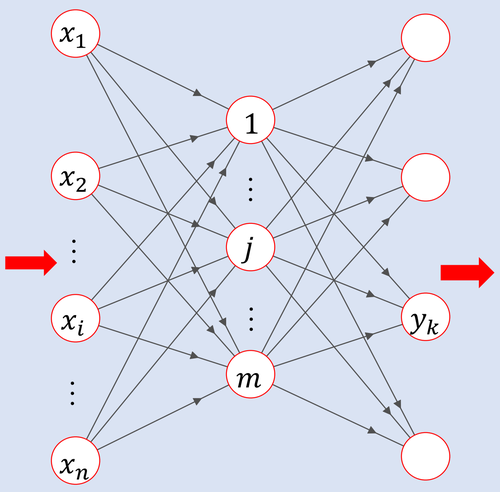
- A surrogate model for laminated stiffened panels



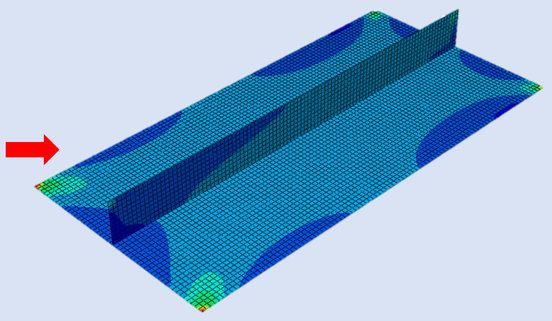
Methods



$$\begin{Bmatrix} N_x \\ N_y \\ N_{xy} \\ M_x \\ M_y \\ M_{xy} \end{Bmatrix} = \begin{bmatrix} A_{11} & A_{12} & A_{16} & B_{11} & B_{12} & B_{16} \\ A_{12} & A_{22} & A_{26} & B_{12} & B_{22} & B_{26} \\ A_{16} & A_{26} & A_{66} & B_{16} & B_{26} & B_{66} \\ B_{11} & B_{12} & B_{16} & D_{11} & D_{12} & D_{16} \\ B_{12} & B_{22} & B_{26} & D_{12} & D_{22} & D_{26} \\ B_{16} & B_{26} & B_{66} & D_{16} & D_{26} & D_{66} \end{bmatrix} \begin{Bmatrix} \varepsilon_{xo} \\ \varepsilon_{yo} \\ \gamma_{xyo} \\ \kappa_x \\ \kappa_y \\ \kappa_{xy} \end{Bmatrix}$$



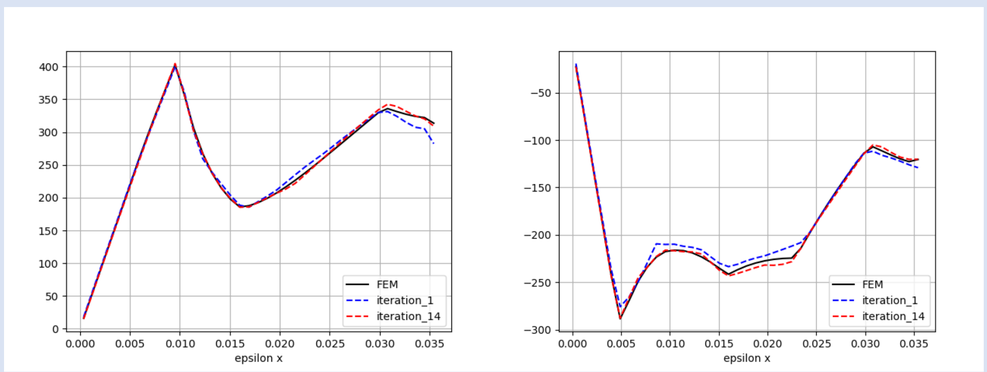
$$\frac{\partial N}{\partial E} = \begin{bmatrix} \frac{\partial N_1}{\partial E_1} & \frac{\partial N_1}{\partial E_2} & \frac{\partial N_1}{\partial E_3} & \frac{\partial N_1}{\partial E_4} & \frac{\partial N_1}{\partial E_5} & \frac{\partial N_1}{\partial E_6} \\ \frac{\partial N_2}{\partial E_1} & \frac{\partial N_2}{\partial E_2} & \frac{\partial N_2}{\partial E_3} & \frac{\partial N_2}{\partial E_4} & \frac{\partial N_2}{\partial E_5} & \frac{\partial N_2}{\partial E_6} \\ \frac{\partial N_3}{\partial E_1} & \frac{\partial N_3}{\partial E_2} & \frac{\partial N_3}{\partial E_3} & \frac{\partial N_3}{\partial E_4} & \frac{\partial N_3}{\partial E_5} & \frac{\partial N_3}{\partial E_6} \\ \frac{\partial N_4}{\partial E_1} & \frac{\partial N_4}{\partial E_2} & \frac{\partial N_4}{\partial E_3} & \frac{\partial N_4}{\partial E_4} & \frac{\partial N_4}{\partial E_5} & \frac{\partial N_4}{\partial E_6} \\ \frac{\partial N_5}{\partial E_1} & \frac{\partial N_5}{\partial E_2} & \frac{\partial N_5}{\partial E_3} & \frac{\partial N_5}{\partial E_4} & \frac{\partial N_5}{\partial E_5} & \frac{\partial N_5}{\partial E_6} \\ \frac{\partial N_6}{\partial E_1} & \frac{\partial N_6}{\partial E_2} & \frac{\partial N_6}{\partial E_3} & \frac{\partial N_6}{\partial E_4} & \frac{\partial N_6}{\partial E_5} & \frac{\partial N_6}{\partial E_6} \end{bmatrix}$$



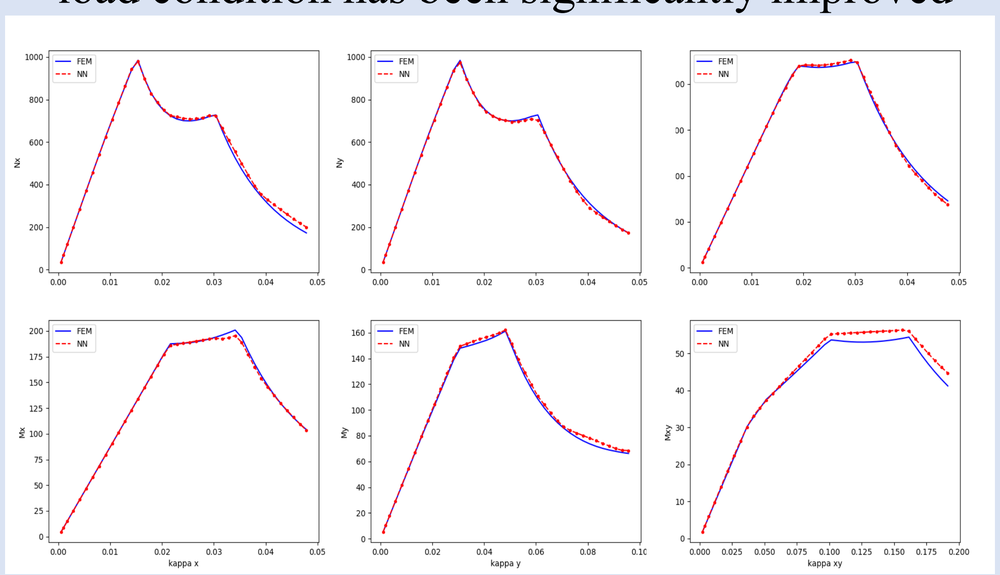
ABAQUS (ugens)

FE model established by CLT | Training | calculate DDNDDE in Fortran | for FE analysis

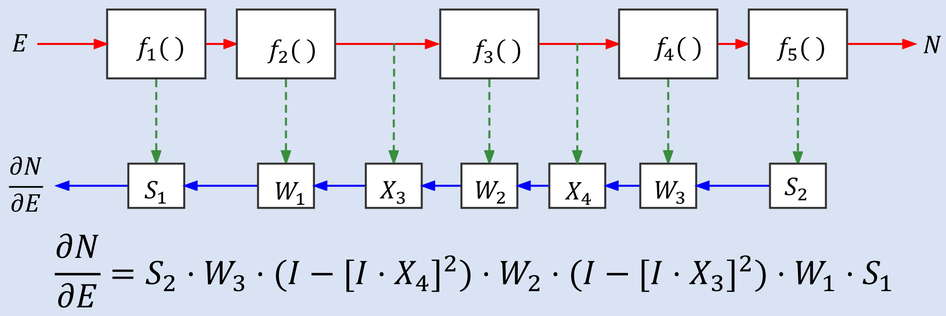
Results & Conclusion



- After 14 iterations, the fitting effect for a specific load condition has been significantly improved

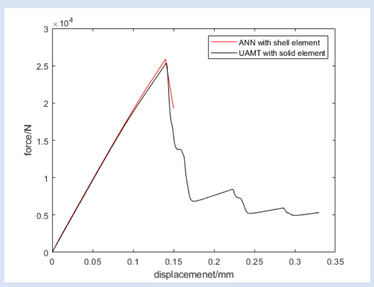


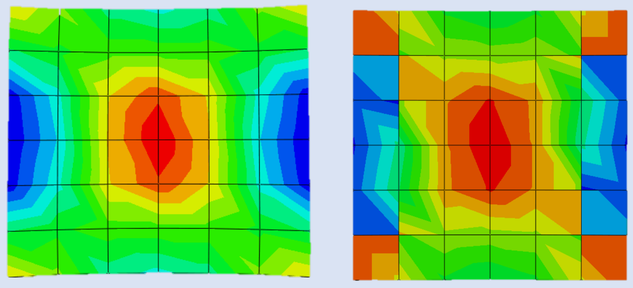
- The results of the individual loading of the six variables indicate that the ANN can proficiently serve as a proxy for the strain-stress relationship.



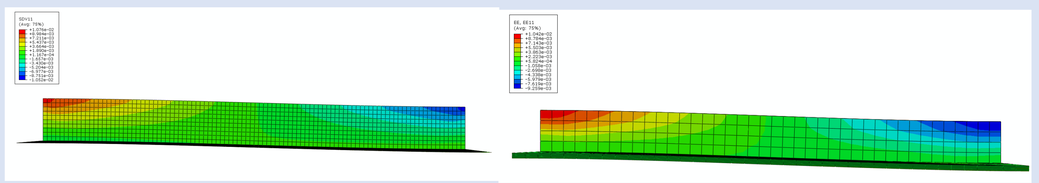
$$\frac{\partial N}{\partial E} = S_2 \cdot W_3 \cdot (I - [I \cdot X_4]^2) \cdot W_2 \cdot (I - [I \cdot X_3]^2) \cdot W_1 \cdot S_1$$

- The computational principle behind the generalized stress and the Jacobian matrix (DDNDDE in ugens).





- The load-displacement curve of tensile in laminated plates, and the strain nephogram in the x-direction



- The strain nephogram of laminated stiffened panels under out-plane load

- The ANN surrogate model, established based on CLT, can effectively reflect the progressive damage process of laminates, and accurately depict the generalized stress-strain relationship experienced by reinforced laminates under out-of-plane loads and other conditions.
- Due to the reduction in the number of elements and conditional and assignment statements, there is also a certain improvement in computational efficiency

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