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

A novel stress-based formulation of finite element analysis

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Cite this as: Himanshu Gaur, Lema Dakssa, Mahmoud Dawood, Nitin Kumar Samaiya, 2021. A novel stress-based formulation of finite element analysis. *Journal of Zhejiang University-SCIENCE A (Applied Physics & Engineering)*, 22(6):481-491. https://doi.org/10.1631/jzus.A2000397

Material input in the nonlinear analysis procedure

True Stress Function

$$\sigma(r) = 473.9e^{0.06458r} - \frac{0.03438}{e^{9.5r}}$$

True Strain Function

$$\varepsilon(r) = 0.01545r + 0.01546$$

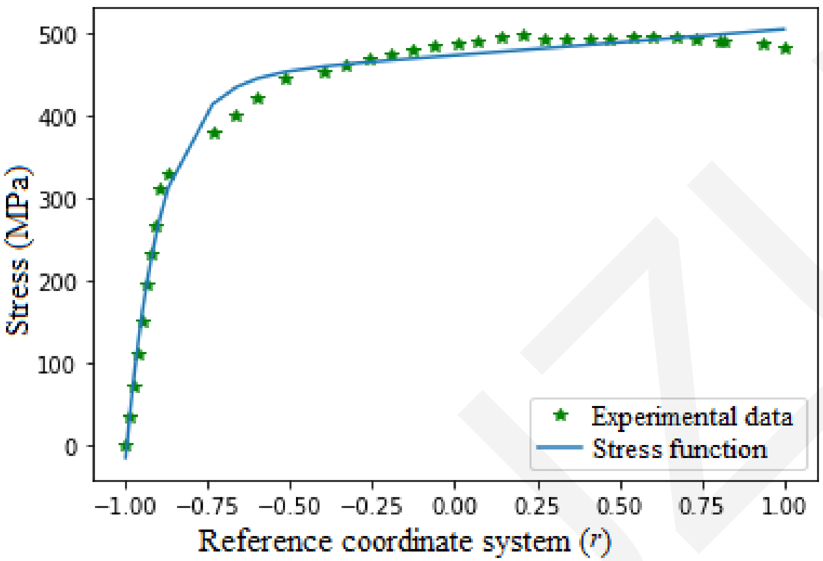

Fig. 1. The variation of the true stress function along with experimental data in the reference coordinate system for mild steel.

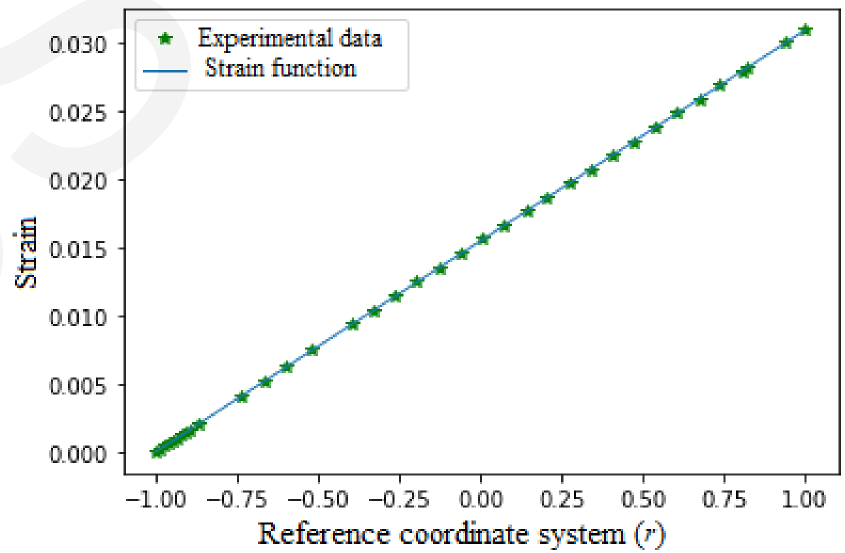

Fig. 2. The variation of the true strain function along with experimental data in the reference coordinate system for mild steel.

Flow chart of analysis procedure

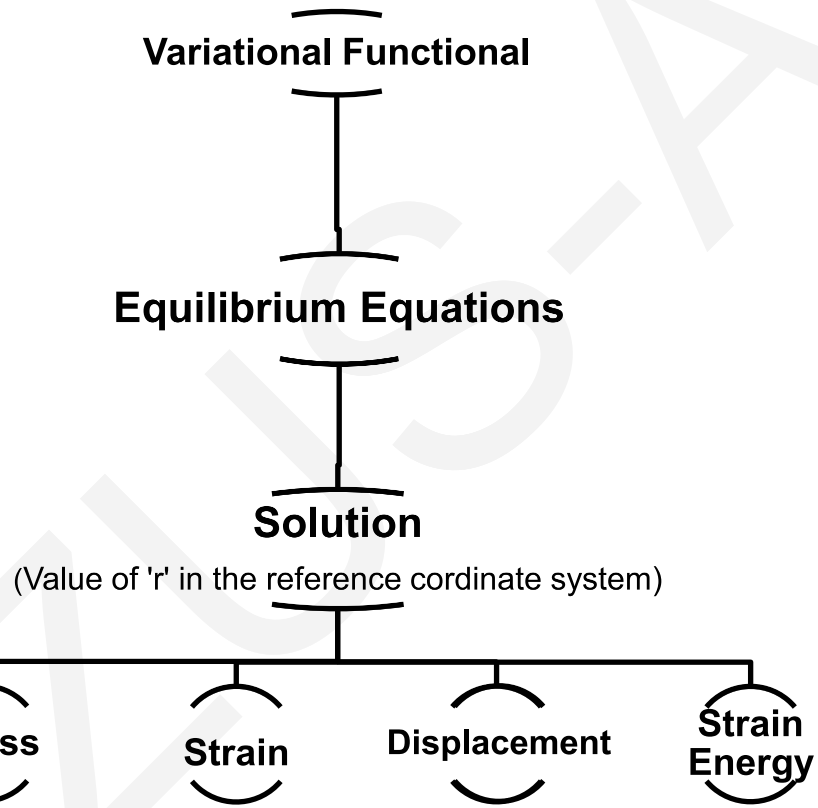

Fig. 3. Flow chart of nonlinear analysis.

Force Equilibrium

Force Equilibrium Equation

$$473.9\, e^{0.06458\, r} - \frac{0.03438}{e^{9.5\, r}} = \frac{F_x}{A}$$

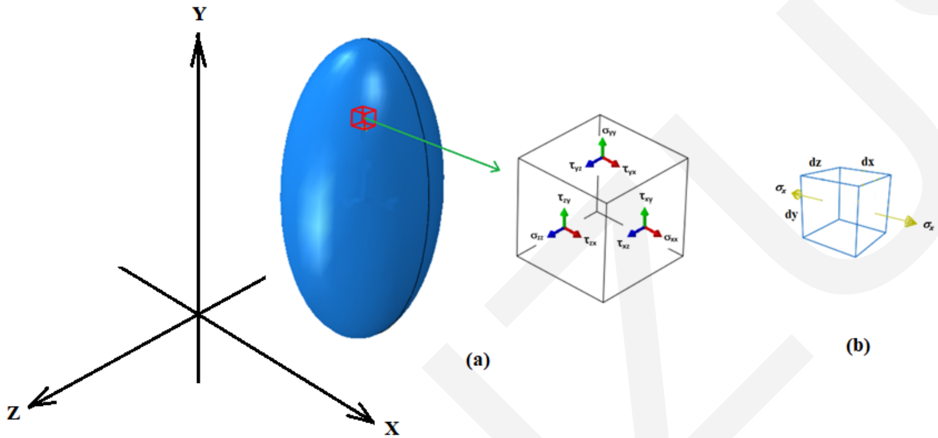

Fig. 4: Three-dimensional coordinate system (a) Stress components in a three-dimensional body (b) A three-dimensional element subjected to uniaxial stress.

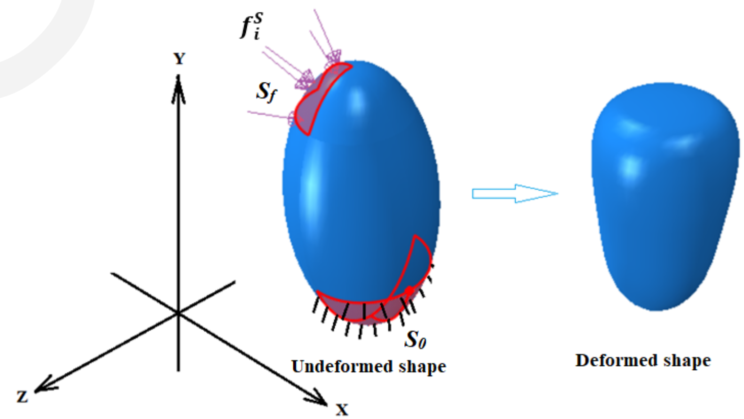

Fig. 5: Three-dimensional body subjected to typical load

Derivation of shear stress and shear strain functions from normal stress and normal strain functions

Shear Stress function derived from Normal stress function

$$\tau_{xy} = \sigma_{xz} = \sigma_{yz} = 473.9\, e^{0.06458\ \mathrm{r}} - \frac{0.03438}{e^{9.5\,\mathrm{r}}}$$

Shear Strain function derived from Normal strain function

$$\gamma_{xy} = \gamma_{xz} = \gamma_{yz} = 21(+\nu)(0.01546\ r + \ 0.01546)$$

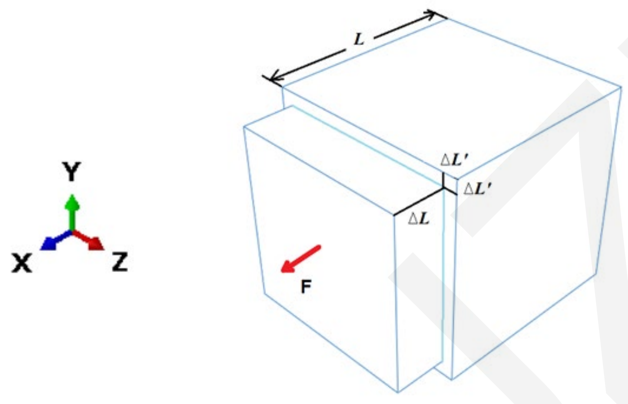

Fig. 6. A 3-D element with uniaxial loading.

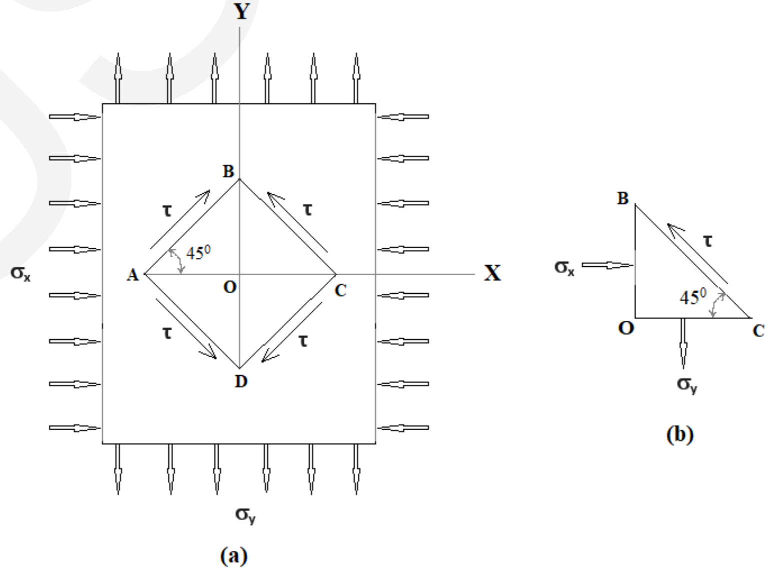

Fig. 7 : Two dimensional plane body (a) Two dimensional sheet subjected to normal stresses. (b) Free body diagram of element OBC.

Results of Uniaxial bar in tension

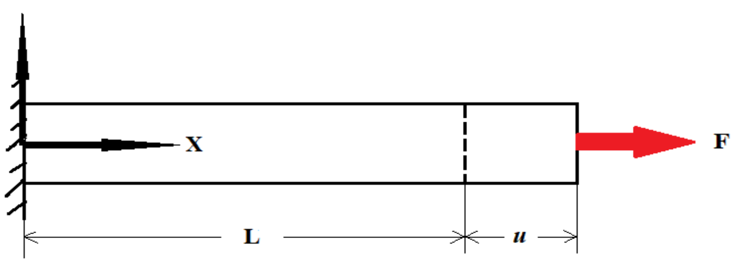

Fig. 8. A bar with uniaxial loading.

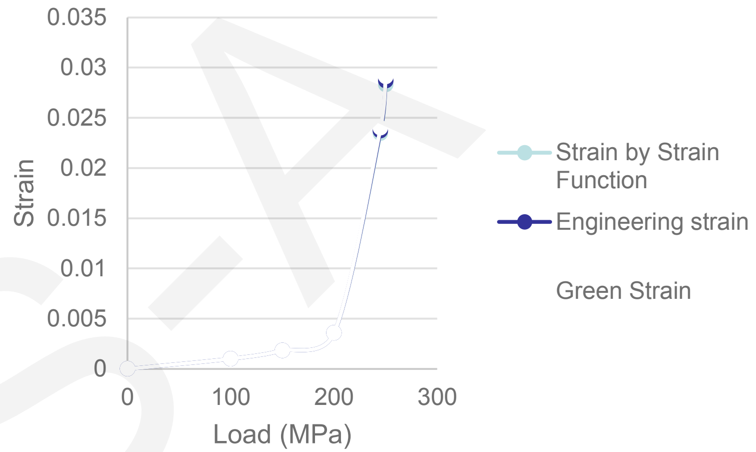

Fig. 9. Comparison of different strain componenents for the bar of uniaxial loading.

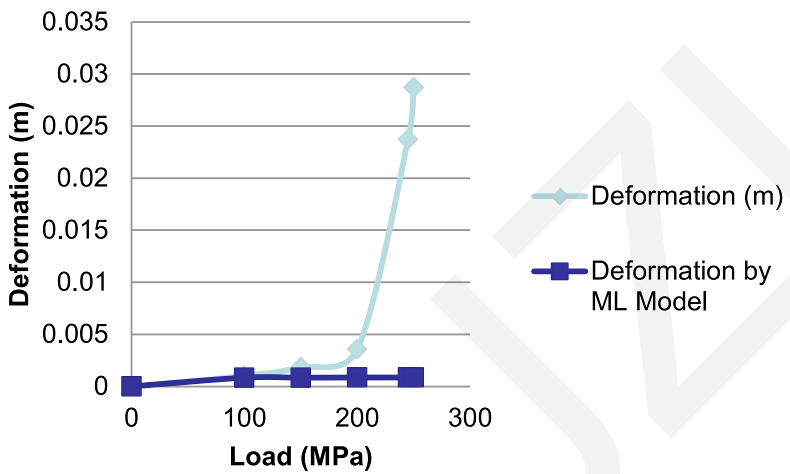

Fig. 10. Comparison of bar deformation by the Machine learning regression model.

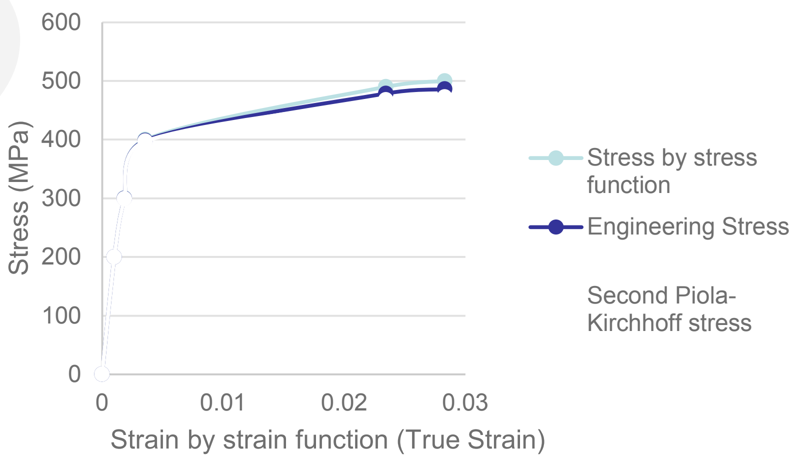

Fig. 11. Comparison of different stress componenents for the bar of uniaxial loading.

Results of crack propagation problem – Beam in pure bending

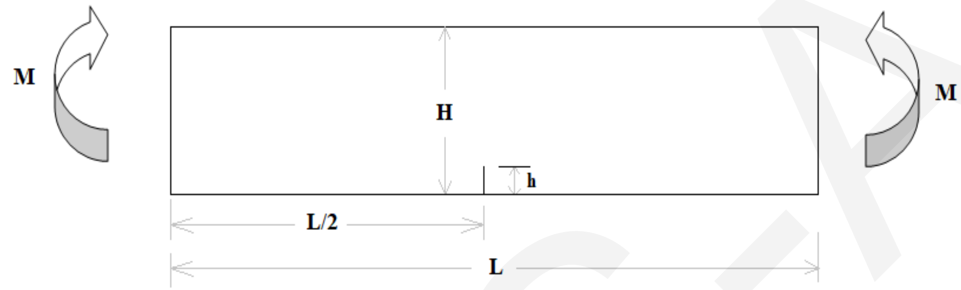

Fig. 12. Steel beam subjected to pure bending.

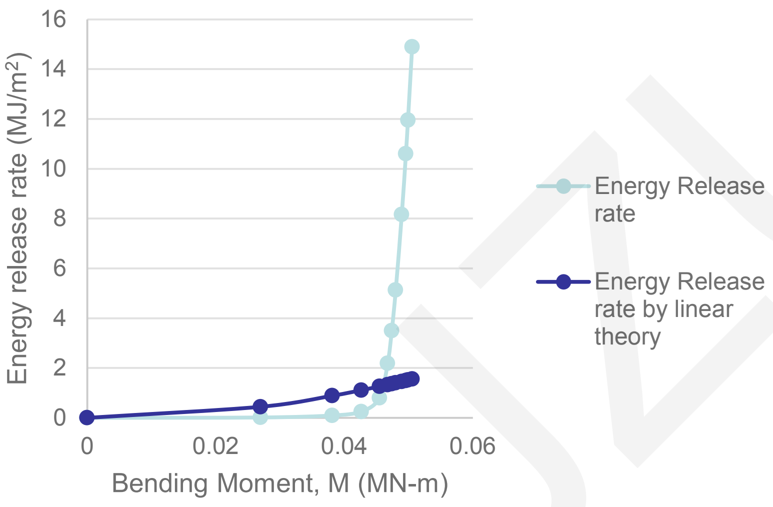

Fig. 13. Energy release rate for the steel beam in pure bending.

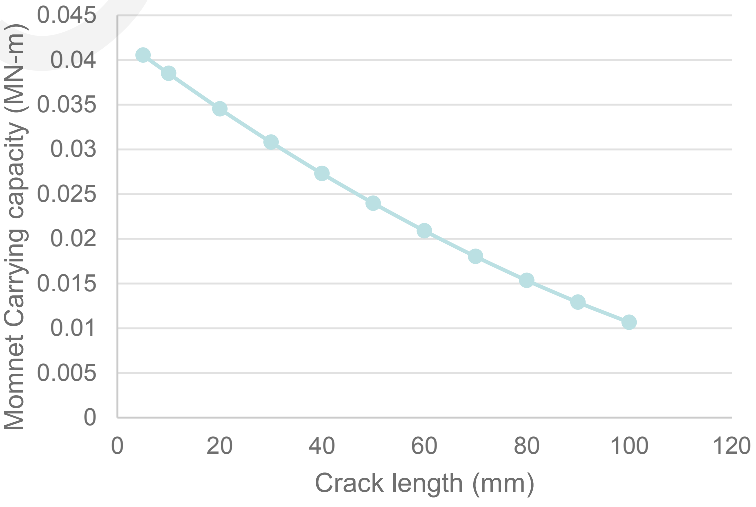

Fig. 14. Maximum bending moment carrying capacity of the steel beam versus crack length.

Conclusions

- Basic derivation and its numerical validation of deriving shear stress and shear strain functions from normal stress and normal strain functions shows the applicability of the methodology for solving three dimensional problems. With the solution of an uniaxial bar loaded axially, it can be concluded that the methodology gives realistic results in plastic range of the material behavior and avoids any hypothetical evaluation of stresses and strains, as it is by using Green strain and Second Piola-Kirchhoff stress in finite element analysis. The accuracy of the solution by using Green strain and Second Piola-Kirchhoff stress in finite element analysis is also measured. From the machine learning regression method it is observed that even neural network does not give accurate results in nonlinear range of the material behavior. In this article, we limit the scope of solving the problems for which discretization is not required but the methodology has the scope of further extension for solving the problems for which discretization is necessary. Accuracy of the method also depends upon nonlinear regression method of machine learning used for curve fitting in Python. The methodology solves a linear, nonlinear, or even the fracture problem with relative ease and simple with high accuracy of results in a real physical sense.

I express my gratitude towards my mentors for their extreme supervision and thank to God for the courage and endurance built in me for carrying out this research work.