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FEM3DD SOFTWARE VERIFICATION

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***Abstract*—**Structural optimization requires a large number of structures to be evaluated. In simultaneous size and shape optimization, where only metaheuristics techniques can be used, the number of evaluations can easily ran into thousands. Renowned and widespread commercial software like ANSYS or MSC Nastran are multipurpose FEM (Finite Element Method) programs have high initialization times which are even higher than the computing ones. This has a vital influence on the algorithm performance, especially in population based metaheuristic techniques. In order to avoid this issue, lighter FEM software or even embedded FEM code should be used. Among the Openware FEM code, the software FEM3DD can be highlighted. From its features, it is worthy to stand out: fast initialization, multi-OS open source code (GNU license), command line operation, CSV and Matlab files reading, and well documented.

***Keywords*—**Structural, optimization, FEM3DD, verification

I. INTRODUCTION

THE price increase of raw materials has forced the engineers to reduce the weight of the structures. This has brought the flowering of a new set of optimization algorithms.

Traditional optimization algorithms do not use simultaneous size and shape optimization, which biases solutions towards local optima. In contrast, new metaheuristics techniques as Genetic Algorithms [1], Evolutionary Strategies [2], Particle Swarm Optimization [3] or Ant Colony Optimization [4, 5] are capable to handle both size and shape variables simultaneously in an easy way. These techniques can lead to lighter structures than traditional Linear Programming [6], Non Linear Programming, Branch and bound [7] algorithms.

The main drawback of this new techniques is that are population based and they require from a large number of evaluations which run from hundreds to thousands, and even millions depending on the structure complexity. This requires the computing time to be very low as on the contrary they become pointless.

Renowned and widespread commercial software like ANSYS or MSC Nastran are multipurpose FEM programs have high initialization times which are even higher than the computing ones. For example, the lighter Ansys v.12.1 startup from command line requires 2 seconds which is usually higher than the structure computing time. To avoid this drawback it is necessary to use a lighter FEM software or even embedded FEM code.

There are a lot of free FEM utilities, some of them even with free open source. Among them FEM3DD is a good choice. The main features of this software are:

1) Fast initialization time for binaries.
2) Binaries for windows, OS X and Linux.
3) Open source code with GNU license [8].
4) Multiple load cases in each analysis with gravity loading, partial trapezoidal loads, thermal loads, and prescribed displacements.
5) Shear deformation effects on geometric stiffness are included.
6) Matlab and spreadsheet interface, graphical output via Gnuplot.

The software uses very common FEM routines, several of them from Numerical Recipes, and is being used by lots of researchers, but the documentation does not show a numerical verification with other renowned software or examples.

The aim of this paper is to do such verification through the evaluation of a set of different structures.

II. EVALUATED STRUCTURES

A. 32 bar roof structure

The structure is an isostatic structure with two supports with point loads on the upper joints.

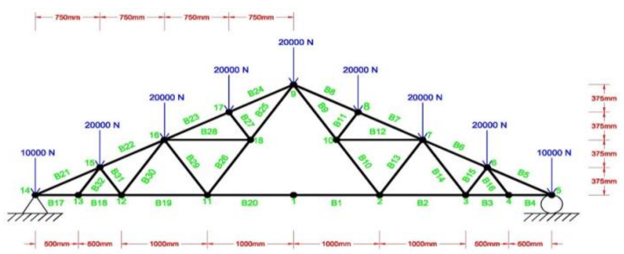

Fig. 1. Geometry of the 32 bar roof truss.

Mechanical properties.
Young Modulus. E = 210000 MPa
Poisson coefficient. N = 0,296
Shear Modulus. G = 81000 MPa
Density. ρ = 7.85E-9 kg/mm^3
Upper and lower bars properties:
Profile : T 40
Transverse section. (A_x): 377 mm^2
Y axis moment of inertia (I_{YY}): 52800 mm^4
Z axis moment of inertia (I_{ZZ}): 25800 mm^4
Polar moment of inertia (J_{XX}): 78600 mm^4
Vertical and diagonal bars properties:
Profile : L 40x4
Transverse section. (A_x): 308 mm^2
Y axis moment of inertia (I_{YY}): 70900 mm^4
Z axis moment of inertia (I_{ZZ}): 18600 mm^4
Polar moment of inertia (J_{XX}): 89500 mm^4

B. Ten bar truss

The structure is very well known in structural optimization and is used as benchmark problem by the researchers to test their algorithms with more than 55 researchers [9] during the last forty years. Fig. 2 shows the best optimum reported with a reduced number of bars.

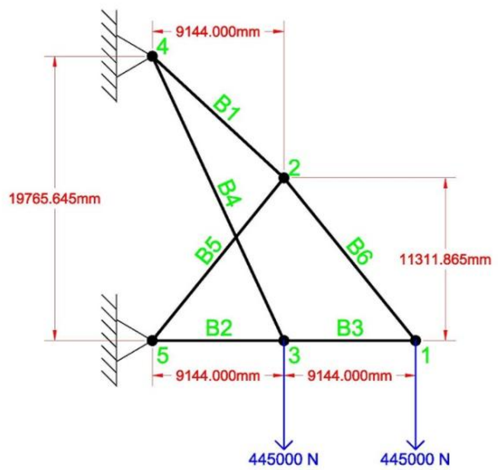

Fig. 2. Geometry of the optimum ten bar truss.

Mechanical properties:
Young Modulus. E = 68900 MPa
Poisson coefficient. N = 0,33
Density. ρ = 2,65851E-9 kg/mm^3
Area B1: 8709,66 mm^2
Area B2: 8709,66 mm^2
Area B3:. 4658,0552 mm^2
Area B4: 3703,2184 mm^2
Area B5: 8709,66 mm^2

C. 22 bar truss

This is also a well-known structure in structural optimization [10].

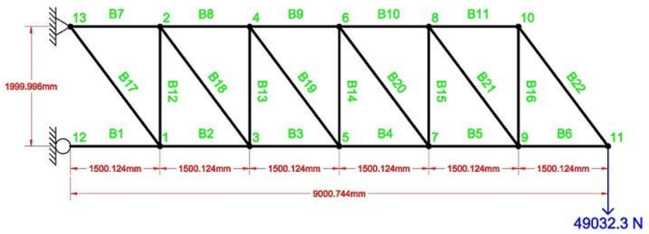

Fig. 3. Geometry of the 22 bar truss.

Mechanical properties.
Young Modulus. E: 68900 MPa
Density. ρ = 2,65851E-7 kg/mm^3
Area B1: 1729,029 mm^2
Area B2: 1729,029 mm^2
Area B3:.1438,707 mm^2
Area B4: 1096,772 mm^2
Area B5: 690,321 mm^2
Area B6: 515,483 mm^2
Area B7: 1438,707 mm^2
Area B8: 1096,772 mm^2
Area B9: 954,837 mm^2
Area B10: 515,483 mm^2
Area B11: 279,354 mm^2
Area B12: 690,321 mm^2
Area B13:.690,321 mm^2
Area B14: 690,321 mm^2
Area B15: 690,321 mm^2
Area B16: 690,321 mm^2
Area B17: 412,257 mm^2
Area B18:. 412,257 mm^2
Area B19: 412,257 mm^2
Area B20: 412,257 mm^2
Area B21: 412,257 mm^2
Area B22: 412,257 mm^2

D. Two supported beam

The structure is an isostatic beam with two supports with several loads and moments.

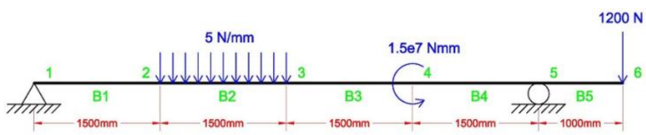

Fig. 4. Geometry of the two supported beam.

Mechanical properties.
Young Modulus. E = 210000 MPa
Poisson coefficient. N = 0,296
Shear Modulus. G = 81000 MPa
Density. ρ = 7.85E-9 kg/mm^3
Profile. IPN 200
Transverse section. (A_x): 3350 mm^2
Y axis moment of inertia (I_{YY}): 21400000 mm^4
Z axis moment of inertia (I_{ZZ}): 1170000 mm^4
Polar moment of inertia (J_{XX}): 22570000 mm^4

III. FEM MODELING

The computing results for verification were obtained using Ansys APDL v12.1.

For the 32 bar roof structure a BEAM54 element with a mesh of ten divisions per bar was used.

For the ten bar truss a LINK1 element was used.

For the 22 bar truss a LINK1 element was used.

For the two supported beam a BEAM3 element with a mesh of twenty divisions per bar was used.

The results given by FEM3DD are: joint loads and displacements, frame element forces and moments, and reactions. So, stresses are not computed by the program and must be subsequently computed.

Following the formulae used for stress computation are shown:

A. Normal axial stress:

$$\sigma_A = \frac{N_X}{A_X} \tag{1}$$

Where:

σ_A is the axial normal stress.
N_X is the axial force.
A_X is the transversal area considered

B. Normal asymmetric bending stress (compression side):

$$\sigma_{F\_C} = \frac{|M_Y| \cdot y_C}{I_Y} + \frac{|M_Z| \cdot z_C}{I_Z} \tag{2}$$

Where:

σ_{F_C} is the bending compressive stress due to bending
M_Y is the bending moment around the local Y axis.
I_Y is the moment of inertia around the local Y axis
y_C is the Y axis distance from the neutral axis to the furthest compression point
M_Z is the bending moment around local Z axis.
I_Z is the moment of inertia around the local Z axis
z_C is the Y axis distance from the neutral axis to the furthest compression point

C. Normal asymmetric bending stress (tensile side)

$$\sigma_{F\_T} = \frac{|M_Y| \cdot y_T}{I_Y} + \frac{|M_Z| \cdot z_T}{I_Z} \tag{3}$$

Where:

σ_{F_T} is the bending tensile stress due to bending
y_T is the Y axis distance from the neutral axis to the farest compression point
z_T is the Y axis distance from the neutral axis to the farest tensile point

D. Average Shear stress along Y axis:

$$\tau_{XY} = \frac{|V_Y|}{A_{SY}} + \frac{|T_X|}{C} \tag{4}$$

Where:

τ_{xy} is the shear stress along Y axis.
V_Y is the Y axis shear force.
A_{SY} is the Shear Area (Collignon Area).
T_X is the torsional moment.
C is the torsion shear constant.

E. Average Shear stress along Z axis:

$$\tau_{XZ} = \frac{|V_Z|}{A_{SZ}} + \frac{|T_X|}{C} \tag{5}$$

Where:

τ_{xz} is the shear stress along Z axis.
V_Z is the Z axis shear force.
A_{SZ} is the Shear Area (Collignon Area).

IV. RESULTS AND DISCUSSION

The verification of the FEM3DD code was done by comparing the computed solutions with the Ansys computed ones. The selected results to make the comparison where: support reactions, joint displacement and bar compound stress.

Once the solutions were computed, the relative error was computed:

$$\varepsilon(\%) = \left| \frac{value_{ansys} - value_{frame3DD}}{value_{ansys}} \right| \cdot 100 \tag{6}$$

Following the results for all the structures are shown.

A. 32 bar roof structure

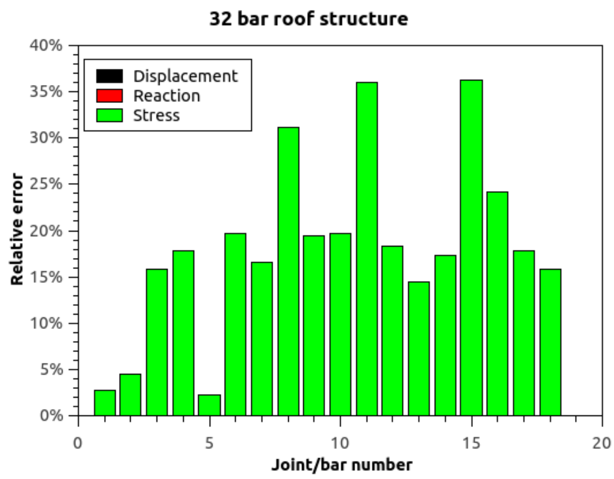

Fig. 5. Relative error of the 32 bar roof structure.

As can be seen the relative error of displacement and reaction is negligible. However, the stress solution shows a large deviation, up to 38%. This can be due to the fact that the stress computation through equations from (1) to (5) is a rough approximation to the real solution.

B. 10 bar truss

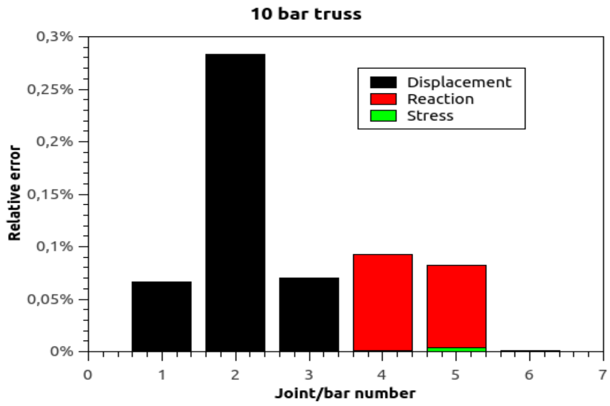

Fig. 6. Relative error of the 10 bar truss.

As Fig. 6 shows the error is negligible.

C. 10 bar truss

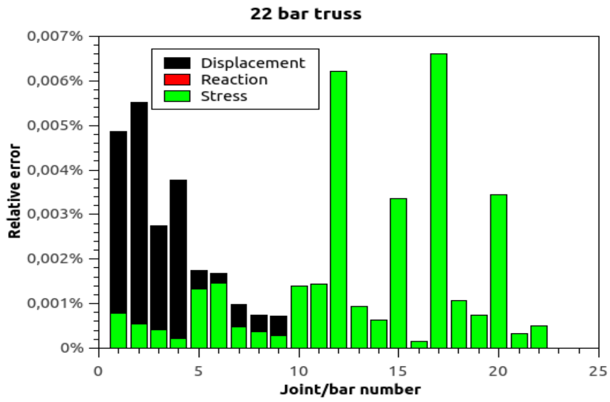

Fig. 7. Relative error of the 22 bar truss.

As Fig. 7 shows the error is negligible.

D. Two supported beam

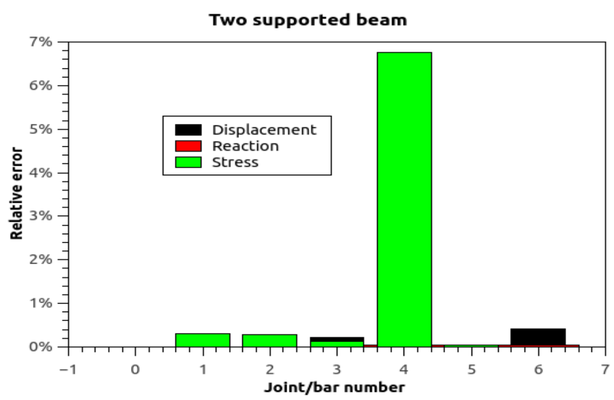

Fig. 8. Relative error of the 22 bar truss.

Like the roof structure, the stress relative error is significant, due to the same effects described before. The reaction and displacement error is negligible.

V. Conclusions

According to the previous analysis, the displacement and reaction differences regarding to Ansys results is negligible. However, the stress results can have a large divergence when working with beam elements due to the fact that the computed results during post-processing are a rough approximation to the real phenomena.

So, when working with beam elements, the computed stresses through FEM3DD should be affected by a safety factor of about 1.5

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