World Transactions on Engineering and Technology Education
Vol.12, No.3, 2014

Hybrid methodology of reverse arbitrary 3D beams geometry analysis with embedded quality tools within the boundaries of a modern CAD system

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ABSTRACT: Modern CAD/CAE systems are essential in all aspects of designing, evaluating and manufacturing engineering parts. Integrating CAE tools in an early design phase within a CAD environment is a state of the art procedure, which enables the engineer to reduce the products design to market time. In this work, a novel hybrid methodology is presented, evaluating and optimising the procedure of obtaining the correct cross-sections of any arbitrary 3D beam. This methodology combines adaptive meshing techniques and quality tools (here the Taguchi Method), within the boundaries of a modern CAD system for the creation of the Boundary Element Method (BEM) mathematical model. The presented methodology will allow students and engineers to broaden their perspective by using embedding tools and methodologies of different engineering science fields; thereby, gaining invaluable experience through computer simulation.

INTRODUCTION

Sagias et al presented an adaptive slicing methodology based on error indicator criteria, in order to determine the correct distance between two consecutive slices on corresponding planes, for the total length of any arbitrary cross section 3D beam [1]. In this article, a novel methodology is introduced, based on the above adaptive meshing procedure, by embedding quality tools, such as the Taguchi method. The presented approach uses DOE (design of experiments), enabling the user to analyse the factors that influence the most and produce values that give better results, minimising at the same time the number of iterations (experiments), when using adaptive meshing techniques for Boundary Element Method (BEM).

METHODOLOGY

A hybrid methodology is presented by combining adaptive meshing techniques and quality tools. The methodology uses the CAD geometrical model of any arbitrary cross-section 3D beam, in order to produce the BEM (Boundary Element Method) mathematical one. Thus, the maximum value of the equivalent stress and its Cartesian position is calculated for every 2D section. The produced sections are based on parallel planes and their distance is calculated based on the value of the estimator (τ_φ). During the development of the methodology it was a necessity to introduce precision to the goal value, but also a tolerance of the limited values that will define the acceptable values (Figure 1).

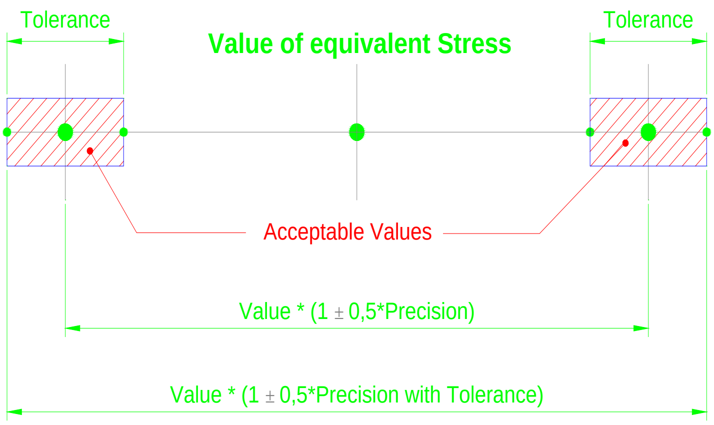

Figure 1: Acceptable values of $\sigma_{vm(i+1)}$ based on $\sigma_{vm(i)}$.

The methodology demands that the distance between two consequent sections should be the same as the difference (τ_{φ}) between the corresponding calculated maximum values of equivalent stress, which should be within limits of the acceptable values. The referred precision ($\overline{\tau_G}$) (Equation 1) is close to what Charafi et al proposed [2], based on the work of Zienkiewicz and Zhu [3], about the error indicator.

$$\tau_{\varphi_{k+1}} = \frac{\sigma_{vm}^{k+1} - \sigma_{vm}^{k}}{\sigma_{vm}^{k}} \cdot 100 \le \overline{\tau_G} \tag{1}$$

Another critical consideration was the value of the initial distance for starting the adaptive procedure between two consecutive sections.

To obtain the optimum *precision* and *tolerance initial distance* values, Taguchi's Robust Design Method was chosen [4][5]. For the analysis of *signal-to-noise* (SN) ratio the *nominal-is-best* (Equation 2) was selected in order to get close to the selected $\overline{\tau_G}$ upper limit, each time [4][5].

$$SN_T = 10 \cdot log\left(\frac{\overline{y}^2}{S^2}\right) \tag{2}$$

IMPLEMENTATION

The methodology was evaluated by implementing a program within the boundaries of a 3D parametric modeller by using its embedded application programming interface (API).

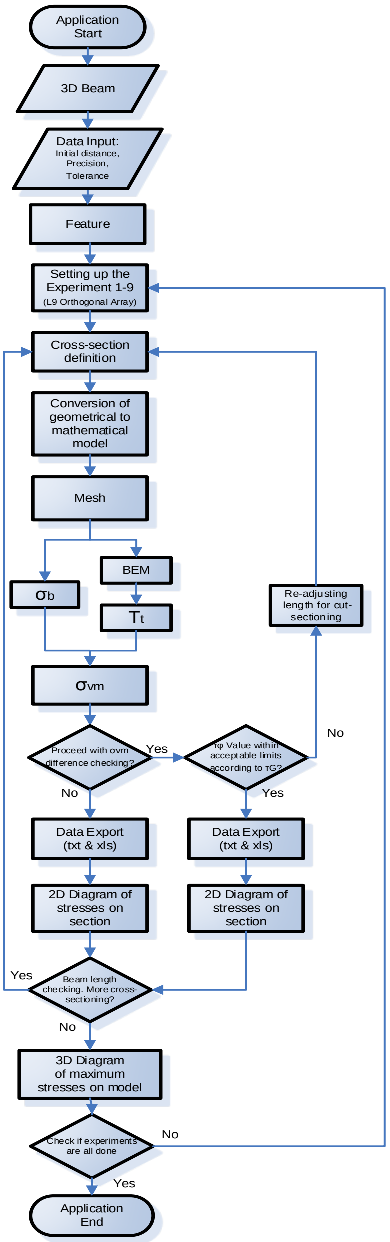

Figure 2: Flowchart of algorithm.

The implemented program calculates the equivalent stress based on bending and torsional moments. The calculations of bending stresses are conducted by using analytical methods and torsional stress calculations are based on the BEM [6][7]. The main procedure is based on previous work [1] but the novelty relies on using Taguchi's robust design, which is need for setting factors and levels [4][5][8]. The factors and levels used in the methodology's case studies are shown in Table 1.

Table 1: Factors with levels used in Taguchi's DOE.

Factor	Level 1	Level 2	Level 3
Initial distance between slices	5 mm	10 mm	15 mm
Tolerance	0.125 %	0.25 %	0.5 %

Based on the factors and levels, the right selection of Taguchi's orthogonal array is the L9. Thus, nine experiments had to be made to obtain the right information for *nominal-is-best* analysis, according to Table 2.

Table 2: Taguchi's L9 DOE.

L9		
Number of experiment	Level of factor 1	Level of factor 2
1	1	1
2	1	2
3	1	3
4	2	1
5	2	2
6	2	3
7	3	1
8	3	2
9	3	3

This $\overline{\tau_G}$ upper limit, as referred by Charafi et al is set to 3% or 5% [2]. In the methodology presented here, three values were used: 3%, 5% and 7%.

IMPLEMENTATION TESTS

In this work case studies are presented by using the implemented program, within the boundaries of a modern 3D parametric CAD modeller. The above mentioned procedure was repeated by setting each time different precision (3%, 5% and 7%) on the taper (20°) extrusion part (30mm), as seen in Figure 3.

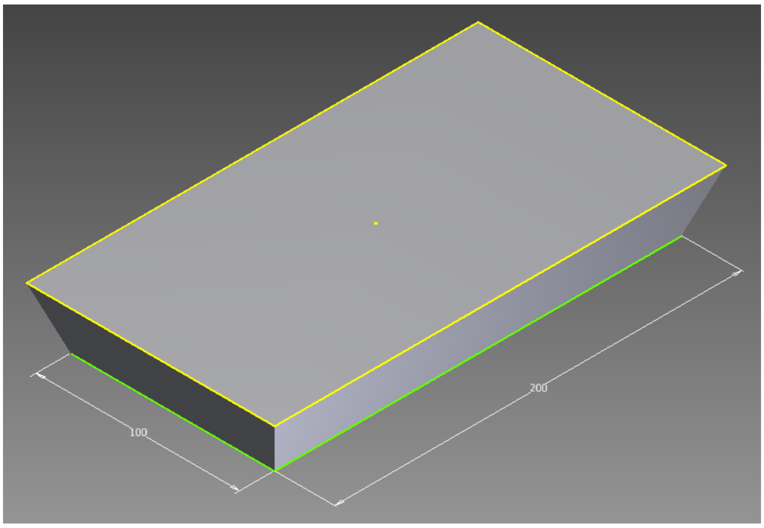

Figure 3: 3D beam - case study.

Table 3 shows the input data used for Taguchi's analysis and Table 4 shows the results.

Table 3: Input data for Taguchi's L9 DOE.

Number of experiment	$\overline{\tau_G}$=3%		$\overline{\tau_G}$=5%		$\overline{\tau_G}$=7%	
	Number of slices	τ_{φ} bar	Number of slices	τ_{φ} bar	Number of slices	τ_{φ} bar
1	18	2.97397	11	4.63952	9	6.43353
2	18	2.97405	11	4.63937	9	6.43376
3	18	2.97424	11	5.10836	9	6.43363
4	18	2.97409	11	4.63949	9	6.43347
5	18	2.97399	11	4.63937	9	6.43392
6	18	2.97418	11	4.63985	9	6.43421
7	18	2.97394	11	4.63933	9	6.43360
8	18	2.80805	11	4.64171	9	6.43355
9	18	2.80758	11	4.63990	9	6.43431

Table 4: Results of Taguchi's analysis.

Level	$\overline{\tau_G}$=3%		$\overline{\tau_G}$=5%		$\overline{\tau_G}$=7%	
	Initial distance between slices	Tolerance	Initial distance between slices	Tolerance	Initial distance between slices	Tolerance
1	2.974	2.974	4.796	4.639	6.434	6.434
2	2.974	2.919	4.640	4.640	6.434	6.434
3	2.861	2.919	4.640	4.796	6.434	6.434
Delta	0.111	0.055	0.156	0.157	0.000	0.001
Rank	1	2	2	1	2	1

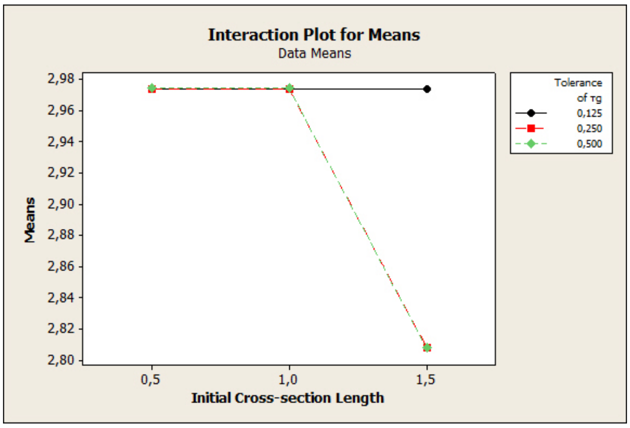

Figure 4: 3% interaction plot.

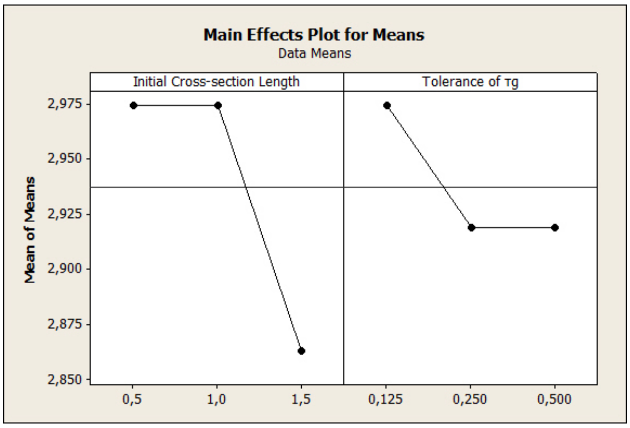

Figure 5: 3% means plot.

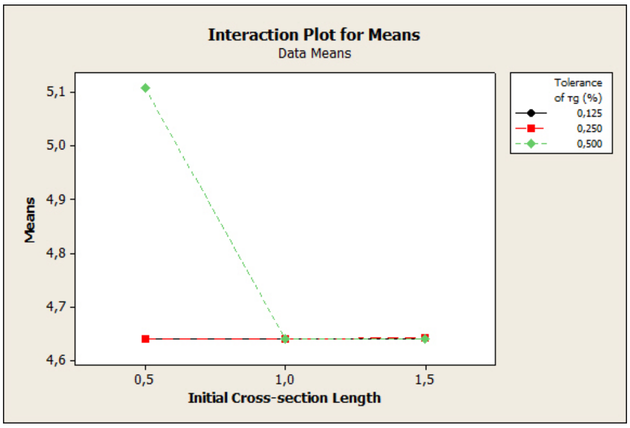

Figure 6: 5% interaction plot.

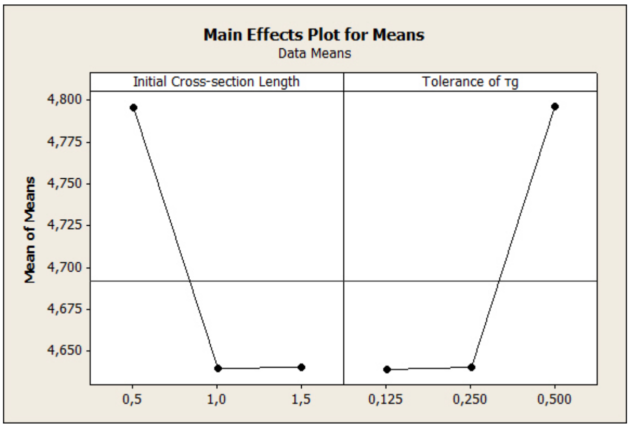

Figure 7: 5% means plot.

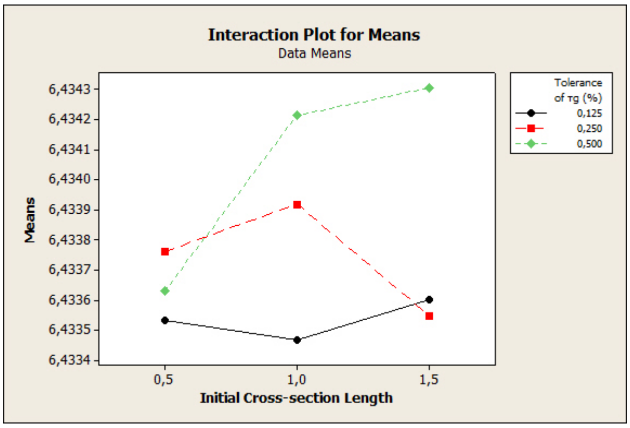

Figure 8: 7% interaction plot.

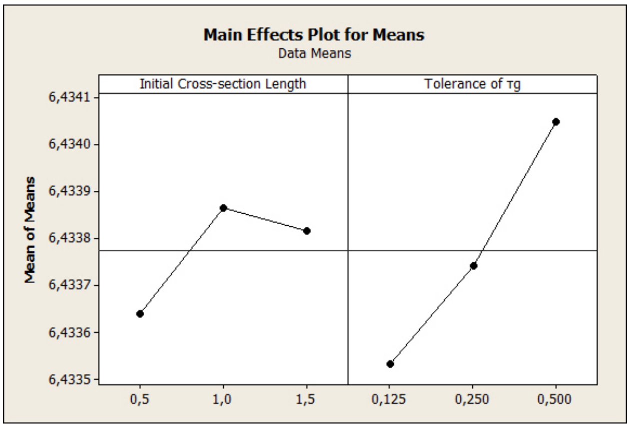

Figure 9: 7% means plot.

From Table 4 and Figures 4-9, the methodology concludes that the optimum combination would be to use $\overline{\tau_G}$=5%, the initial distance of slice 5mm and tolerance set to 0.5%, resulting in 11 slices as shown in Figure 10.

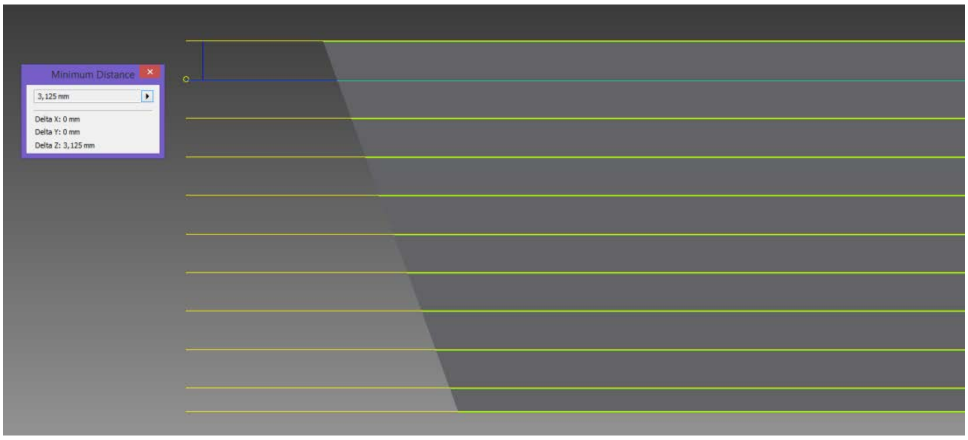

Figure 10: Final slicing model.

IMPACT ON ENGINEERING AND TECHNOLOGY EDUCATION

The methodology's implementation and all case studies were conducted in TEI Piraeus Mechanical Engineering Department’s CAD Laboratory. The presented methodology’s main novelty is the successful implementation of Taguchi quality tools in the adaptive slicing procedure by correctly reconstructing the CAD geometry to obtain the BEM model. Through the presented methodology students and engineers can expand their perspective by embedding tools and methodologies of different engineering science fields, gaining invaluable experience through computer simulation.

CONCLUSIONS

A novel hybrid methodology has been presented in this work, one which uses a typical CAD geometry structure (Non-Rational B-Splines/NURBS, Boundary Representation/B-Rep), adaptive meshing techniques and quality tools (Taguchi’s DOE), in order to produce optimal stress analysis results through a slicing procedure of the geometrical model by using the Boundary Element Method (BEM). The methodology uses quality tools in order to define the minimum number of needed iterations in repeatable adaptive processes. The iterations are handled as experiments in the Taguchi quality tool, having the optimum solution as their goal. Combining different types of technology and exploring how they inter-operate, gives more accurate results in a shorter time and provides understanding of how factors interact with the goal result.

The methodology is promising and could be extended to future work by embedding other quality tools, such as response surface methodology (RSM) that will enable even more accurate results to be obtained. Inserting time minimisation as a goal, but also exploring the possibility of using tools such as linear programming (LP), by creating mathematical models, could also lead to interesting results.

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