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Proceeding Paper

Sensitivity Analysis of Internally Reinforced Beams Subjected to Three-Point Bending Load †

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Abstract: This work focused on the study of efficient solutions for the improvement of the mechanical behavior and movement capability of industrial devices with mobile parts subjected to three-point bending load. To achieve the aim of developing efficient engineering solutions, several stages were followed. A sensitivity analysis was done to one of the beams in order to determine the influence of each variable in the mass and in the displacement's parameter space. It has been shown that parameterizing the ANSYS input file is effective for finding out how sensitive is the system to the design variables studied. The results of the sensitivity analysis may be used in the future to choose the variable weights that will be used in optimization techniques and processes. Further study might be done in the future, to attempt to find a way to generalize the methodology for different models and/or in different situations.

Keywords: finite element method; static analysis; sensitivity analysis

1. Introduction

In numerous applications involving industrial apparatus, the load accelerates electrically motor-driven moving components. These actuators accelerate twelve times more rapidly than gravity. Accelerations necessitate structures that are more rigid and robust. Stiffness influences equipment efficacy more than strength. Accelerations can cause equipment deflection and output reduction. Increased vibrations may lead to complications [1]. Geometric optimization increases stiffness more so than material selection [2]. Geometry may increase the stiffness of a burden. The combination of mass and deflections is more effective than deflections alone. By reducing the size of industrial machinery with movable components, it is possible to increase their speed without diminishing their mechanical performance. Because they can be reinforced internally [3,4] and are firmer per mass, hollow solid sections are more engineering-friendly than bulk beams with the same outer section dimension and section shape. Plates and casings need to be rigid. The rigidification of the ribbed, webbed, and curved walls. This objective necessitates the previous two. Ribs and webbing provide reinforcement for thin-walled components [5]. Few studies have examined structural steel's stiffening. These aircraft structures, which have been in use since the beginning of the 20th century, may have been investigated in the past [6]. Orlov states that ribs increase moment of inertia and strength. Vieira and colleagues investigated the mechanics of structural stiffening. This effort could benefit from the author's design. If effective reinforcement designs are applied to the beams investigated in this paper, the mass unit mechanical behavior can be improved [7]. The authors investigated reinforcement of structural beams. Thin-walled steel columns reinforced by Liu

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increase their bending and torsion strength without increasing their weight. Steel beam dynamics are influenced by transverse ribs [9]. Under various load regimens, the same author evaluated the spatial stability of rib-reinforced thin-walled beams. Differential equations were solved by orthogonalization of Bubnov–Galerkin. Problems were resolved by analyzing and substantiating circumstances. Eigenvalue problems are transformed from general solutions. Experiments confirmed the validity of the method. It is computed [10]. Liu and Gan-non welded plates to a loaded W-shaped steel girder. Reinforcement patterns, welding preload magnitudes, and unreinforced beam defects were modeled using the Finite Element Method [11]. In [12], the type, size, and location of stiffeners were proposed. This effort improves the mechanical performance of thin-walled beams by adding ribs, lattice, and sandwich panels to rectangular hollow-box beams.

2. Materials and Methods

The sensitivity analysis utilized a single Finite Element Model (FEM) model. The FEM model with applied loading and degrees of freedom (DOF) constraints is depicted in Figure 1 (left). Several keypoints have been selected to depict the data presented in this article, as shown in Figure 1 (right).

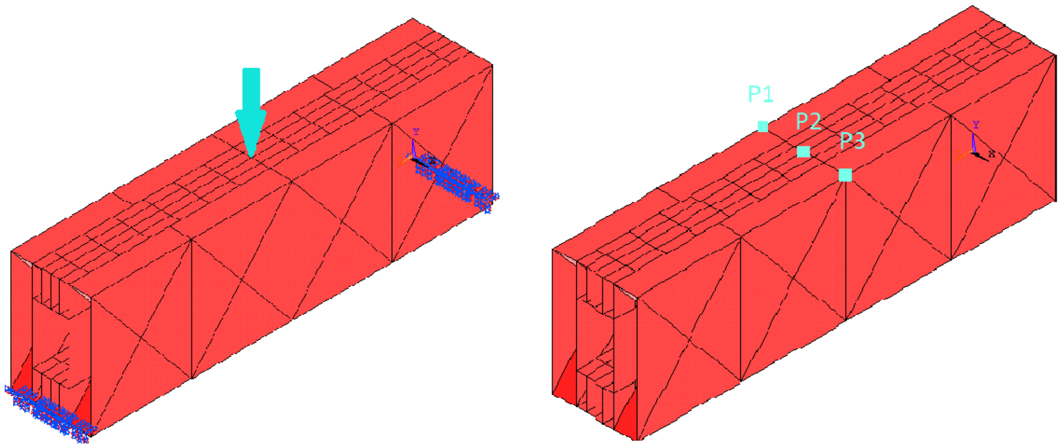
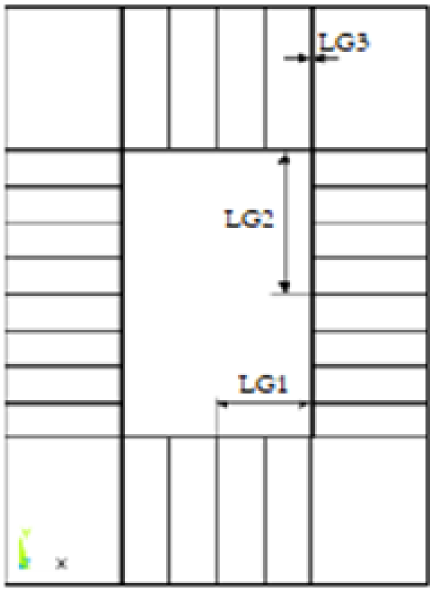


Figure 1. Applied load and DOF constraints (**left**); points used to calculate displacements on sensitivity analysis procedure (**right**) [13].

These keypoints were chosen because their coordinates are unaffected by a change in the variable values during optimization. As these areas are extensively reinforced with ribs, it is not anticipated that the thin material at the under consideration thicknesses will result in significant local deformation. This was demonstrated by analyzing large deformation in terms of geometrical nonlinearity. The outcome is identical to that of a linear static analysis. Providing an analysis falls outside the scope of this endeavor at this time. During the evaluation of the thickness variable LG3, values between 2 and 4 mm are considered. The thickness remains unchanged at 3 mm in all other instances. Clearly, the laterals have a greater effect on the results than the initial beams subject to torsion stresses. The sandwich panel is subservient to the lateral reinforcements from a mechanical standpoint. Thus, the height of the intermediate compartments is diminished. These sites were selected at locations where changes in geometric variables do not influence any coordinates. This eliminates the direct impact of changes to design variables on the results. Requesting local results from points whose coordinates change as geometric variables change would be misleading. For each set of variable values, one would capture data from the same points (P1, P2, and P3), but these points have distinct coordinates, i.e., they are in a different zone of the model. This article makes use of the material characteristics E = 210 GPA, 7890 kg/m^3, and 0.29 [-] Poisson coefficient. The applied load intensity is N, the element type is SHELL63, and the average lattice element size is 2.5 mm. For each model's sensitivity analysis, the following three design variables were chosen:

Figure 2 shows the geometric variables *LG1*, *LG2* and *LG3* on Beam 1—Pattern 1.



LG1 is the distance from the center of the bean to the inner wall of the beam in the direction of the section width.

LG2 is the distance from the center of the section of the beam to the inner wall of the beam in the direction of the section height.

LG3 is the thickness of all the walls of the beam

Figure 2. Geometric variables of the FEM model used on the sensitivity analysis [13].

The outer section dimensions are generally maintained. It is assumed, from an industrial standpoint, that all beams will be constructed with panels of identical thickness. The goal is to obtain a set of reinforcements that is straightforward to assemble on a large scale.

3. Results and Discussion

3.1. Mesh Convergence

In order to get accurate results, a mesh sensitivity analysis was done in ANSYS Mechanical APDL. Element sizes of 2.5, 5, 10, 20 and 40 mm were used. Four refinement levels were defined, in order to compare the results of a mesh size with the ones with double element size. The y deflection was measured in points P1, P2 and P3, shown in Figure 1 (right). The results of the mesh convergence analysis are shown in Figure 3.

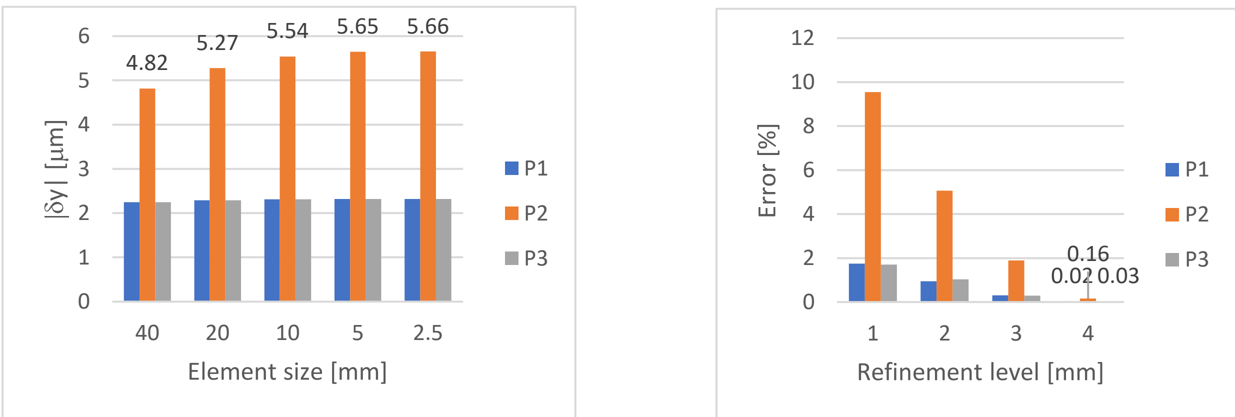


Figure 3. Mesh convergence analysis of the FEM model used on the sensitivity analysis.

As expected, mesh refinement increases the accuracy of results, as they vary less with decreasing element size. The element size of 2.5 mm was selected, as it originates accurate results, with maximum error of 0.16%.

3.2. Sensitivity Analysis

This section contains graphs generated from Tables 1–3. ANSYS MECHANICAL APDL was used to generate Tables 1–3 by modifying one variable at a time and repeatedly executing the ANSYS input file. Other variables are held constant in geometry. Nonetheless, the beam's mass varies when a single geometric variable is altered. The linearity of the relationship between the variables and the deflections and between the variables and the mass was determined using a linear fit. Displays numerical and statistical information. Because the figures depict the total deflection of the three selected points in relation to the variable's values and approximate trendlines, this is the case. In contrast, the Tables illustrate the masses and deflections of the obtained beams at each of the locations P1, P2, and P3.

Table 1. Sensitivity analysis for the LG1 variable under bending loads (left) and Figure 3 Variation of the *z* deflections with the LG1 variable under bending (right).

	j = 1	j = 2	j = 3	j = 4	j = 5
LG1	0.035	0.04	0.045	0.05	0.055
mass [kg]	82.762	81.567	80.372	79.176	77.981
δyP1 [m]	−1.84E−06	−1.95E−06	−2.06E−06	−2.18E−06	−2.29E−06
δyP2 [m]	−6.52E−06	−6.58E−06	−6.63E−06	−6.67E−06	−6.71E−06
δyP3 [m]	−1.84E−06	−1.95E−06	−2.06E−06	−2.18E−06	−2.29E−06
δsum [m]	1.02E−05	1.05E−05	1.08E−05	1.10E−05	1.13E−05

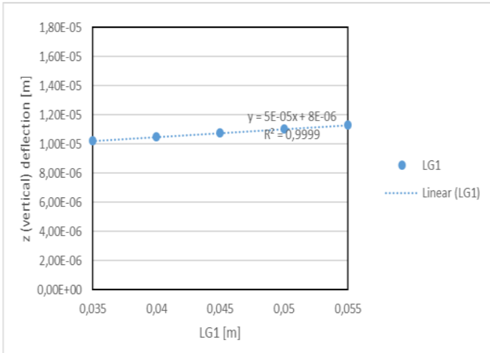


Table 2. Sensitivity analysis for the LG2 variable under bending loads (left) and Figure 4 Variation of the *z* deflections with the LG2 variable under bending (right).

	j = 1	j = 2	j = 3	j = 4	j = 5
LG2	0.065	0.07	0.075	0.08	0.085
mass [kg]	82.346	81.359	80.372	79.384	78.397
δyP1 [m]	−2.02E−06	−2.04E−06	−2.06E−06	−2.08E−06	−2.10E−06
δyP2 [m]	−6.41E−06	−6.51E−06	−6.63E−06	−6.75E−06	−6.90E−06
δyP3 [m]	−2.02E−06	−2.04E−06	−2.06E−06	−2.08E−06	−2.10E−06
δsum [m]	1.05E−05	1.06E−05	1.08E−05	1.09E−05	1.11E−05

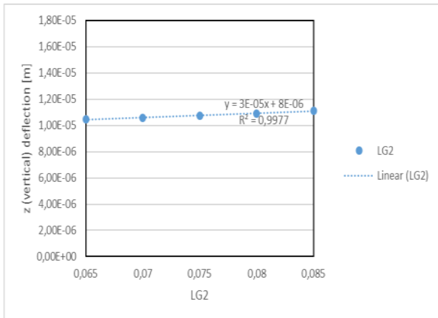
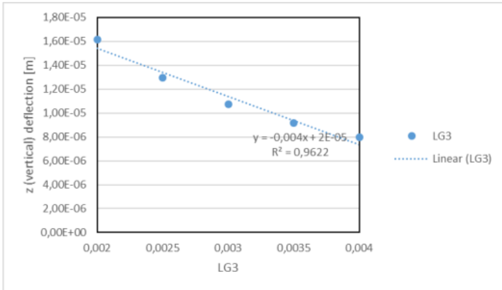


Table 3. Sensitivity analysis for the LG3 variable under bending loads (left) and Figure 5 Variation of the *z* deflections with the LG3 variable under bending (right).

	j = 1	j = 2	J = 3	j = 4	j = 5
LG3	0.002	0.0025	0.003	0.0035	0.004
mass [kg]	53.581	66.976	80.372	93.767	107.162
δyP1 [m]	−2.67E−06	−2.34E−06	−2.06E−06	−1.84E−06	−1.65E−06
δyP2 [m]	−1.08E−05	−8.27E−06	−6.63E−06	−5.49E−06	−4.66E−06
δyP3 [m]	−2.67E−06	−2.34E−06	−2.06E−06	−1.84E−06	−1.65E−06
δsum [m]	1.62E−05	1.29E−05	1.08E−05	9.17E−06	7.97E−06



The deflection increases strictly as the LG1 and LG2 variables increase but decreases as the LG3 variable increases. It can be seen that the results at points P1 and P3 are identical. The results are expressed as a single series representing the aggregate of the absolute deflections at locations P1, P2, and P3. It is also possible to observe that the beams' deflections are in the micrometer range, which, for applied load intensities of 1500 N in three-point bending and taking into consideration the beams' thinness, indicates the beams' excellent stiffness. Table5-4.7 represents the sensitivity analysis.

In terms of sensitivity, variable LG3 is the most sensitive. This is expected, as this variable is applied to all the walls of the beam, so its influence is total, while the influence of LG1 and LG2 on the mechanical behavior of the beam is partial.

4. Conclusions

Evidently, all the selected geometric variables LG1, LG2, and LG3 are adequate for optimization objectives. The results suggest that the FEM model's deflections are sensitive to them. Initial variable values were specified in order to enable a large search space. The models are constrained geometrically, primarily in terms of their inner section. The values of the variables LG1 and LG2 cannot be so low as to cause structural elements from the sides or top/bottom to collide, preventing further optimization evaluations. This precludes the discovery of an optimal solution. Otherwise, the interior ribs will be smaller than the average element size, leading to defects. LG3 is the least essential variable in this regard. Nevertheless, it must be high enough to prevent substantial nonlinear effects in future practical applications, while remaining low enough to permit the production of lightweight components suitable for the applications intended by this work. It has been shown that parameterizing the ANSYS input file is an effective way to determine the system's sensitivity to the investigated design variables. The results of the sensitivity analysis may be used in the future to determine the variable weights for optimization techniques and processes. This study has the weaknesses of only presenting an analysis for a single beam. The generalization of the findings for similar beams with slightly different geometries is, therefore, not possible. The limitations of the methodology are, therefore, not being unable to obtain a generalized model that allows us to predict the sensitivity of the studied variables for similar beams, with slightly different geometry. Nevertheless, the study allows us to prove that the three geometric variables are useful for design optimization purposes.

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