MODAL ANALYSIS OF SLENDER CURVED BEAMS PRELOADED THROUGH CLAMPING

R. Helfrich, N. Wagner
(INTES GmbH, Germany)

Abstract

The current work is inspired by a recent work of Mignolet et. al. entitled 'Stochastic modal models of slender uncertain curved beams preloaded through clamping'. An initially curved beam is forced fit into a clamped-clamped fixture designed for straight beams. The centerline of the curved beam is described by a truncated series of assumed shape functions of a pinned-pinned beam, where the coefficients are zero mean Gaussian random variables with certain standard deviations according to the fact that the peak of the profile is less than one thickness. The two-dimensional shell mesh that represents the rectangular cross section is then extruded along the centerline of the beam to generate the solid mesh of the beam. Thus, the main difference between the two approaches lies in the fact, that the beam model is replaced by a solid model in the current study to achieve a more realistic description of the contact behaviour between the fixture and the beam. The assembly process consists of a geometric nonlinear static analysis including frictional contacts between the clamping blocks and the beam. The beam itself is essentially supported by contact forces. So-called compensations springs are introduced automatically in VisPER (Visual PERMAS) to suppress rigid body modes during the contact analysis. At the beginning of the analysis the blocks were moved path-controlled towards the beam until the gap between the lower and upper blocks corresponds with the thickness of the slender beam. A different treatment of normal and tangential directions of frictional contacts is available when the contact state is known. Thus multipoint constraints can be applied independently in normal and tangential direction. Besides that, the actual contact pressure may be used to introduce a further kind of fuzziness with respect to active areas in the contact zones. That means that once the actual contact pressure exceeds a certain threshold, multipoint constraints are automatically introduced to couple guiding and dependent nodes. The second step is generally used to replace active contacts by multipoint constraints in order to linearize the nonlinear contacts and to make it possible to perform an eigenvalue analysis afterwards. Here, the geometric stiffness matrix of the pre-stressed structure is taken into account. Finally, the influence of various physical and geometrical system parameters such as the friction coefficient, beam profile and contact pressure on the eigenfrequencies of the assembly is seamlessly

investigated by means of a sampling procedure. All computations are carried out in PERMAS. Solver specific commands are highlighted by a preceding dollar sign and capital letters in the subsequent sections.

1. Overview

Different clamping conditions have a distinct effect on the dynamic behaviour of jointed structures. Åkesson [1] conducted an experimental modal analysis of boring bars. The results demonstrate that the different controlled clamping conditions yield different dynamic properties of the clamped boring bars. Carpinteri [4] investigated the influence of applied axial loads on the fundamental vibration frequency of slender beams. Druesne [6] proposed numerical parametric methods for predicting the effect of uncertainties in the input parameters on the natural frequencies of structures. Mignolet [7] considered a nonparametric stochastic modelling approach of structures with uncertain boundary conditions. Treyssède [8] studied pre-bending effects upon the vibrational modes of thermally pre-stressed planar beams. Tison [5] used a fuzzy approach to describe the behaviour of mechanical systems with uncertain boundary conditions.

2. Computational Experiment

The finite element model consists of 288 linear hexahedral elements for the clamping blocks and 2000 elements for the slender beam Fig. 1. Boundary conditions are illustrated by red, green and red arrows according to x, y and $z-$direction. The arrows are oriented towards the corresponding node in case of inhomogeneous boundary conditions ($PRESCRIBED) and opposite direction for homogeneous boundary conditions ($SUPPRESS). Translational and rotational degrees of freedom are marked by single and double arrows, respectively.

Figure 1: Finite element model of the clamping fixture and beam

The geometrical and physical properties of the clamping fixture and beam are listed in Table 1.

Table 1: Geometrical and physical properties of the assembly

Length of clamping block l_{cb} [mm]	38.1
Length of the beam (clamp to clamp) l_b [mm]	228.6
Young's modulus E [GPa]	204.7
Poisson's ratio ν	0.28
Density ρ [kg/m^3]	7860.
Friction coefficient μ	0.3

Two surface to node contacts are defined between the adjacent surfaces of clamping blocks and the lower and upper surface of the beam, respectively. All contacts are easily defined through the Contact Wizard in VisPER (Visual PERMAS) [10].The clamping block with a coarse mesh is the guiding partner of the contact.

Figure 2: CA-Wizard

The initial gap between the blocks and the beam is closed by moving the clamping blocks towards the beam, until the distance between opposite clamping blocks match the thickness of the initially curved beam.

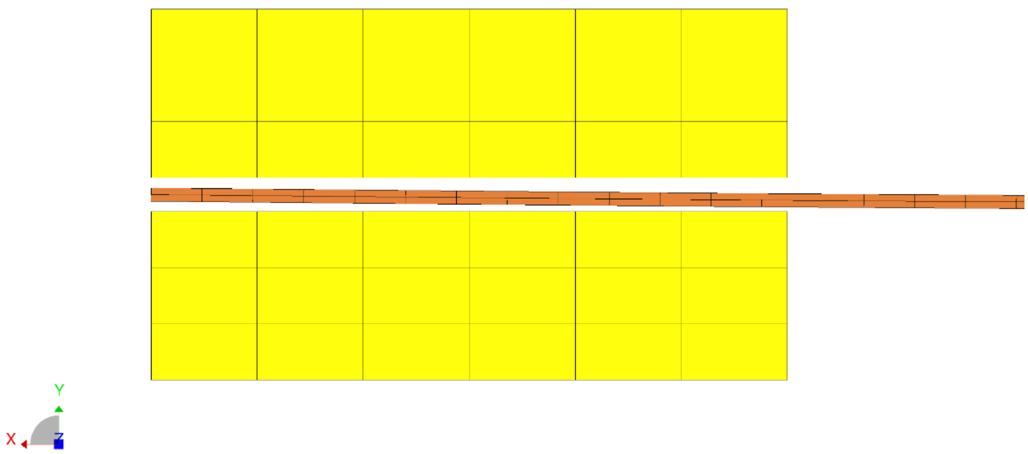

Figure 3: Detailed view of the clamping fixture

A geometrically nonlinear static analysis is conducted in the first step. The contact pressure distribution is illustrated in Fig. 4.

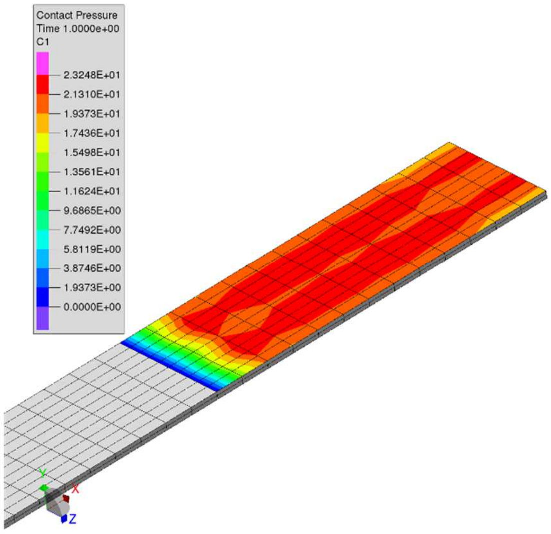

Figure 4: Contact pressure distribution

The displacement field at the end of the first step is used to update the nodal point coordinates. All active contacts are automatically replaced by general MPC's using $CONTLOCK. There exist various options to configure the behaviour of the contact linearization. Besides different handling of normal and tangential directions additional limits for minimum contact pressure, normal contact force, frictional force, gap width, etc. can be specified for each contact definition. A complete overview is available in the user's reference manual [9].

Based on the linearized contact, a real eigenvalue analysis is performed. Case A denotes the case, where active contacts are locked in normal and tangential directions, case B considers the scenario where the tangential direction is free. Obviously, configuration A tends to be stiffer. A threshold value for the minimum contact pressure $\sigma_{\min}$ = 20 N/mm^2 is applied in case C. All active contact zones with lower contact pressure are neglected. Thus the number of multipoint constraints decreases. Therefore the eigenfrequencies decrease as well.

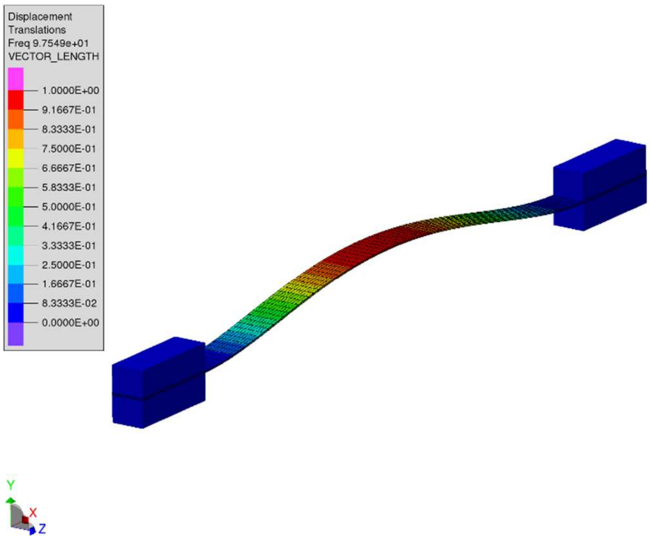

Figure 5: First bending mode

Table 2: Eigenfrequencies of the coupled system

	Case A	Case B	Case C
Mode i	f_i [Hz]	f_i [Hz]	f_i [Hz]
1st Bending mode	97.5	92.1	88.8
2nd Bending mode	214.9	213.7	202.8
3rd Bending mode	424.2	421.2	400.4
4th Bending mode	697.7	693.9	658.5
1st Torsional mode	868.6	875.0	852.4

3. Conclusions

The analysis of dynamic properties such as eigenfrequencies of slender bars concerning different clamping conditions are discussed. As part of the examination of variability of eigenfrequencies in jointed structures, the engineer should consider a more realistic description of couplings to improve the confidence intervals of natural frequencies. A tied contact is rarely an accurate description in real-world applications.

4. References

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