On the Influence of Arching and Material on the Vibration of a Shell - Towards Understanding the Soloist Violin

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Abstract

A study of the results of FEM simulations of plate and shell models are presented to reference of a violin vibrations problems. The influence of arching, variable thickness and damping was considered. ABAQUS/Explicit procedure of "*Dynamic Explicit*" was used in the simulation. Anisotropy in the material properties (spruce) was considered (9 elastic constants).

Keywords: bridge mobility, shell arching, variable thickness, damping, FEM

1. Introduction

A common way to produce the top of the violin is to profile its outer side. Afterwards the inner side of the violin's plate is worked and its thickness is initially set. The plate is carefully worked until its thickness reaches the final value. Only the inner side of the plate is profiled in the final phase of the work, the outer arches are not. The way of working invites to investigate how plate's thickness adjustments affect the properties of the finished violin. Only the effect of thickness reduction can be investigated. While none change of outer arching can be investigated. This limitation of the design is overcame by the use of FEM modelling by ABAQUS. Furthermore the influence of material properties can be efficiently investigated by simulation.

The vibrational properties of a physical system can be summarized by its resonances. An efficient way to begin is to measure the admittance of the system. An optimal way is to use an impulse excitation by a pendulum and to measure the vibration response in the given time period. This can easily be adapted to measure the admittance, mobility of the violin [6].

The mobility response of a Stradivarius violin measured in this way is shown in *Acoustics for violin and guitar makers* Fig. 7.6. [2]. There are clear resonance peaks at low frequencies (LF), below 1000 Hz. There are no clear peaks at higher frequencies but rather a "hump" with a maximum around 2.5 kHz. This hump is called a bridge hill (BH) [1, 3-5]. The LF single peaks range and 2.5 kHz hump range are investigated by the phase and vibration response divided by the driving force. A typical French violin has a different arching and it has no BH-hump.

The mobility response of a newly made violin by S. Niewczyk is also shown in *Acoustics for violin and guitar makers* [2] in the Figure 7.24. Again there are a clear resonance peaks in low frequency range and a BH frequency range. But in this case the BH frequency range has a rather peaked maximum. The response shape in the high frequencies is little affected by the violin bridge and the violin sound post. The sound post of a violin mainly sets the balance between the low and high frequency properties. It can be used to adjust the low frequency resonances.

Vibrational properties of a violin can be modelled by a rectangular plate with a bridge and a rough modelled f-holes [6] (see Figure 1). This model is used in this paper. The effect on vibrational properties of thickness, arching and material properties can thus be modelled by ABAQUS. The modelling can be done in a reference to a real physical system both for frequency responses and vibration modes. The paper includes an investigation on how the vibrating properties depend on the thickness of the plate, the plate arching and material properties.

The results of such a simulations can be compared to the results of vibration measurements of the violin. Since placing a vibration transducer on the violin's plate would chance its vibrational properties, the measurements should be done by non-contact method using laser vibrometer as it is done while testing the low-vibroactive devices [7].

2. FEM simulation

Simulations in ABAQUS/Explicit FE system were used to compare:

- the plate indicated as plEJ with the arched shell shEJ - both based in corners on springs and dashpots,
- plate plEJ with arched shell shEJ – based on pinned outside edges,
- arched shells with uniform thickness and with various nodal thickness – minimum thickness = 2 mm, maximum thickness = 5 mm,
- influence of damping on vibration.

In all FE models the following properties were used:

Basic dimensions. Plate plEJ and arched shell shEJ have the same basic dimensions: Outside dimensions – 363 x 210 mm, thickness – 4.5 mm, dimensions and positions of f-holes. Arched shell shEJ has the high of 13 mm and the radiuses R_1 equal to 430.54 mm and R_2 equal to 1273.51 mm. The 4-mm-thick bridge is the same for all cases.

Load excitation. In all cases the same impact load was applied in one of the bridge corners - see Figure 1. Output response was analysed in the opposite bridge corner.

Boundary conditions. In the first case outside corners are based on springs and dashpots (foam models). In all other cases the structures are based on the pinned outside edges.

Material property. Both the plate and the shell have spruce properties (9 elastic constants) that are shown below. For the bridge made of maple an isotropic material was applied. Its properties are presented in the Table 1.

Table 1. Selected properties of spruce and maple

	Young's modulus	Density	Poisson's ratio
plEJ and shEJ	$E_L = E_x = 9.7$ GPa $E_R = E_y = 0.55$ GPa	$\rho = 460$ kg/m^3	$\nu_{xy} = 0.44$, $\nu_{xz} = 0.33$, $\nu_{yz} = 0.42$
Bridge	$E = 10$ GPa	$\rho = 600$ kg/m^3	$\nu = 0.43$

Additional properties for spruce were taken from E. K. Askenazi [8].

Mesh. The plate plEJ and arched shell shEJ have very similar meshes in terms of division and number of elements – see Figure 1. Both have elements type shell S4R, the plate plEJ has 631 elements and the shell shEJ has 608 elements.

Procedure. The *Dynamic Explicit* procedure of ABAQUS/Explicit was used for all analysed cases, 0.2-second-long time period was analysed. Output field – every unit time 5E-5 [s].

2.1. *Plate plEJ and arched shell shEJ - based on springs and dashpots in corners*

The plate plEJ is the same model of the plate that was used in the experiment, presented in the previous work [6]. Additionally, the arched shell shEJ simulation was done to study the influence of the convexity on response of the bridge corner compared to the plate plEJ.

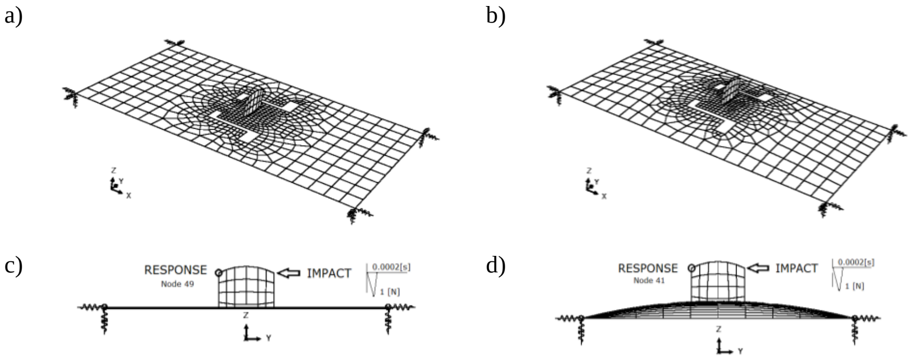

Figure 1. FEM models: a) model of the plate plEJ; b) model of the arched shell shEJ; c, d) nodes of the load (IMPACT) and response

Time histories (Figure 2) show that responses of plEJ and shEJ have similar frequencies. The main comparison of the responses, the admittance is shown in the Figure 3. The graph on the left side shows a frequency range from 0.2 to 5 kHz. There are clear differences between admittances in this frequency range from 0.2 to 0.5 kHz. In the range from 0.5 to 5 kHz the differences' visibility is small. The graph (Figure 3) on the right side shows a frequency range from 2 to 5 kHz. In this range the activity of BH is shown very clearly.

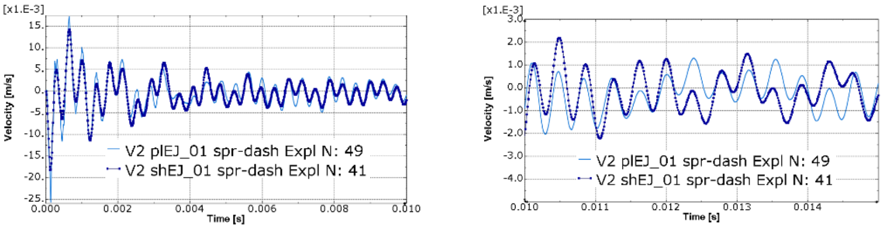

Figure 2. Time history (velocity V2 - Vy) - response in the bridges corners (see Figure 1) of the plate plEJ and the shell shEJ. Rectangle corners are based on springs and dashpots

The admittance values of shEJ are slightly lower than the admittance of plEJ in this frequency range. Only in the range of BH the left top overlaps.

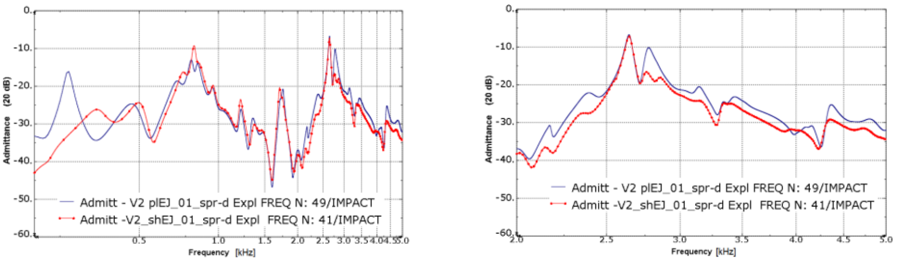

Figure 3. Admittance – plEJ - node N49, shEJ arched - node N41.
Boundary conditions – the corners of rectangle are based on springs and dashpots

2.2. *Plate plEJ and arched shell shEJ – based on pinned outside edges*

In the Figure 4 a comparison of the responses is shown as the admittance for the new boundary conditions – pinned edges. The graph on the left side shows a frequency range from 0.2 to 5 kHz. Similarly to subsection 2.1 there are clear differences between admittances in the range from 0.2 to 1.2 kHz. In the range from 1.2 to 5 kHz the differences' visibility is small.

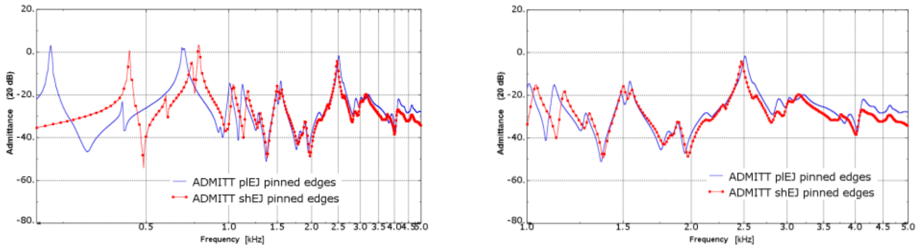

Figure 4. Admittance – plEJ - node N49, shEJ arched - node N41.
Boundary conditions – outside edges are pinned

The graph (Figure 4) on the right side shows a frequency range from 1 to 5 kHz. In this range activity of BH is shown very clearly too. The admittance values of shEJ are slightly lower than the admittance of plEJ in this frequency range from 2 to 5 kHz. Only in area of the left side of the top of the BH the admittances overlap.

2.3. *Arched shells shEJ with uniform thickness (4.5 mm) and with various nodal thickness – min. thickness = 2 mm, max. thickness = 5 mm*

Results of arched shell shEJ with uniform thickness of 4.5 [mm] are already shown in Figure 4. Additionally, the same model of shEJ with various thickness was considered to study the influence of thickness on response of the bridge corner. Pinned edges as boundary conditions were used in both models.

For shEJ with various thickness shell section was defined by “Nodal distribution” option. Nodal thickness was defined proportionally to the height of the shell. The arched shell shEJ model is 13-mm-heigh. For the height of 0 mm (pinned edges) thickness is equal to 2 mm and for the height of 13 mm the shell top thickness is equal 5 mm.

The left graph in the Figure 5 shows a frequency range from 0.2 – 5 kHz. The right graph shows a range of frequency from1.5 – 5 kHz.

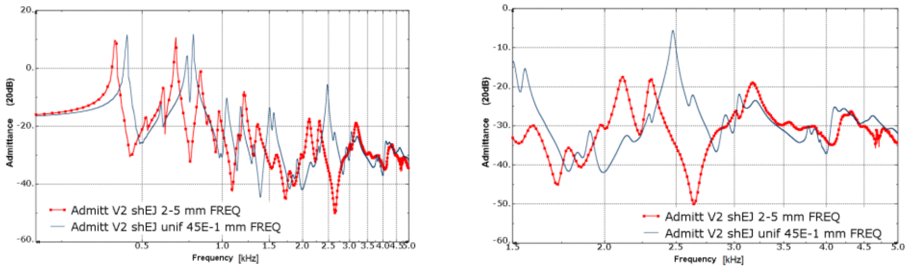

Figure 5. Admittance of shEJ with uniform thickness - 4.5 mm (blue) and shEJ with various thickness – 2 mm to 5 mm (red). Thickness increases with high of the shell

In the Figure 5, the differences of admittance between the shell with a constant thickness and the shell of varying thickness are clearly visible.

2.4. *Influence of damping on vibration*

Material structural damping can only be used in mode based procedures. This damping will be ignored during dynamic procedure (ABAQUS/Explicit).

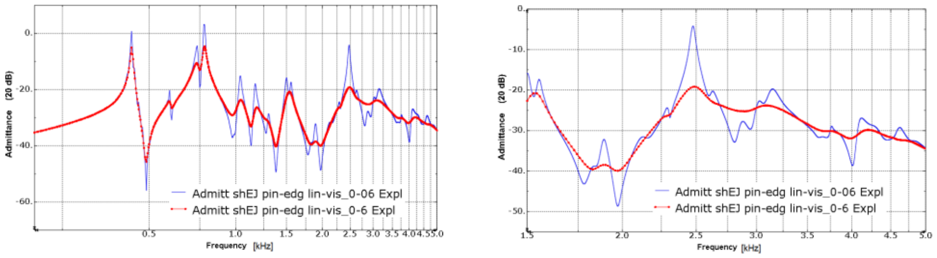

Figure 6. Admittance of shEJ with two values of linear bulk viscosity parameter – 0.06m (default, blue) and 0.6 (red)

In ABAQUS/Explicit dynamic procedure – linear bulk viscosity parameter and quadratic bulk viscosity parameter are used to determine the damping. Default values are: 0.06 for linear bulk viscosity parameter and 1.2 for quadratic bulk viscosity parameter. Two values of linear viscosity parameter were used to simulate responses: 0.06 - default value and 0.6 - strong damping.

3. Conclusions

Basing on the study of Figures 3-6 the following conclusions can be formulated:

Comparisons of the plate and the shell admittances that are shown in the Figure 3 and the Figure 4 present rather small differences between the plate and the shell, especially in the frequency range from 1 to 5 kHz. The arched shell admittance has lower values than the plate admittance. The Figure 3 (corners on springs) shows BH with double tops and the Figure 4 (pinned edges) presents BH with clear single top.

In the low frequencies range (100 – 500 Hz) the differences are distinct.

The Figure 5 shows the influence of variable shell thickness on the admittance and the shape of BH. It is therefore possible to influence the shape of BH through the change of local thicknesses of the shell.

A clearer observation of the shape of the admittance is possible through the introduction of damping (Figure 6).

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