

Bracing effect in a guitar top board by vibration experiment and modal analysis

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1. Introduction

The authors have developed composites of polyurethane foam reinforced anisotropically with carbon fibers, which have almost the same vibration properties as Sitka spruce (Sp) for use in musical instrument soundboards [1,2]. Guitars with top boards made of these composites had frequency and transient characteristics comparable to those of popular wooden guitars, and it was shown that they had sufficient potential for use as substitute materials for soundboard construction [3].

As the procurement of wood for soundboards has not yet become impossible, to realize the appearance of guitars with a composite top board at present, it is necessary to make the most of the composite's advantages with regard to acoustic characteristics. Wooden guitars can show excellent timbre with complex gluing of bracing to the top board. There have been a few studies on guitar bracing [4]. However, the bracing patterns and methods are still derived from tradition and based on luthiers' experience. To achieve our purpose, it is necessary to characterize the bracing effect. In this study, the bracing effect was investigated in a vibration experiment and by modal analysis of the top boards. The results indicated the possibility of designing a composite top board with no bracing with the same mode characteristics as a wooden top board with bracing.

2. Specimens

Two replicas of a wooden guitar top board with and without bracing were made. They were the same wooden top board as used in electric-acoustic guitars available commercially. The replicas were fixed tightly with a wooden frame 50 mm in thickness. Their appearances and manner of bracing are shown in Fig. 1.

3. Experiment and analysis

3.1. Experimental procedures

The frequency response and Chladni figure were measured for guitar top board replicas. The replicas were excited from the back of the bridge point, where a small iron piece was glued, with an electromagnetic driver and the vibration was detected at the bridge point with a condenser microphone located 1 mm from the surface. The frequency characteristics in each replica were measured in the form of a transfer function by sweeping frequencies with an FFT analyzer. In Chladni experiments, sand was scattered on the face of the replica, and the replicas were excited from the back by a loudspeaker.

3.2. FEM analysis

Modal analysis of the top boards was performed using the FEM program, ANSYS. Analysis models had the same shape and size as the top plate replicas. Around the models was fixed and they had zero degrees of freedom. Physical values of typical Sp described previously [5] were used for analysis. Tetrahedral elements (3-D 20-node structural solid element Solid95) were used for meshing models, and top board models with and without bracing had 14310 and 13069 nodes, respectively.

4. Results and discussion

Chladni figures could be observed to the 2nd mode in the replica with bracing and to the 9th mode in the replica with no bracing. Examples of vibration mode figures determined from the Chladni figures and those determined by the analyses are shown with eigenfrequencies in Fig. 2(a) and Fig. 2(b), respectively. In these figures, (1) is the 1st mode in the replica with bracing, (2) is the 1st mode in the replica with no bracing, and (3) is the 8th mode in the replica with no bracing. As shown in the figure, the vibration modes determined by FEM analysis agreed well with the Chladni figures. In comparison with the eigenfrequencies determined from the Chladni figures, those determined by FEM in the wooden replica with and without bracing were almost the same and higher by slightly less than 30%, respectively. To investigate the differences in eigenfrequency in the wooden replica with no bracing, the same experiment and analyses were carried out for an isotropic acrylic resin replica; the eigenfrequencies and mode figures in both agreed with a high degree of accuracy. Based on these results, the vibration modes of the top board could be simulated accurately, though there still remained some problems in the anisotropic top board with no bracing. Comparison of (1) with (2) in Fig. 2 indicated that the bracing made the top board isotropic. The frequency responses of the top board replicas with and without bracing are shown in Fig. 3. As shown in the figure, the bracing caused the resonant frequencies to be higher and made the frequency response characteristic smooth. This can be seen clearly in Fig. 4, which shows the bracing effect at frequencies of less than 10 kHz by modal analysis. The resonant frequency increased by 2.5 kHz at the 200th mode with bracing. Therefore, bracing results in good sound from top boards in the high frequency range.

The composite top board with no bracing showing the same mode characteristics as the wooden top board with



Fig. 1 Top plate replicas with and without bracing.

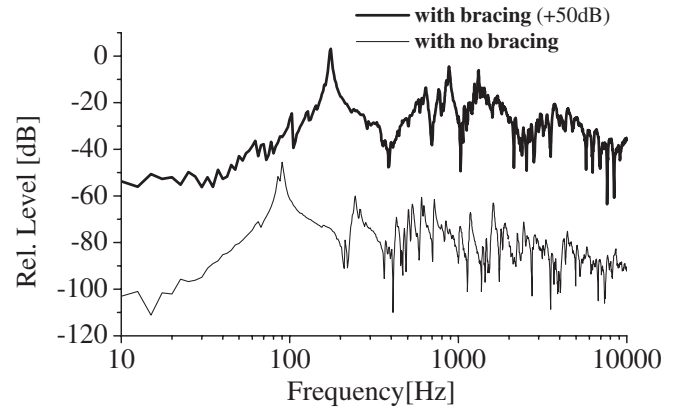


Fig. 3 Frequency responses of guitar top board replicas.

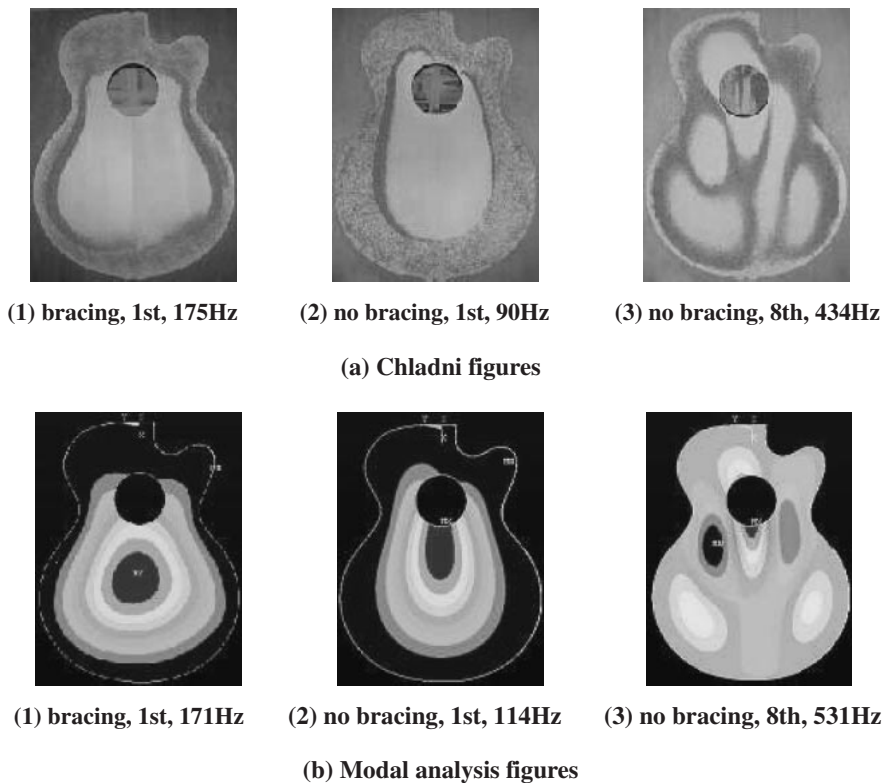


Fig. 2 Figures of Chladni and modal analyses.

bracing was simulated as an example of guitar design. As shown in Fig. 4, the design was possible using the following physical values [5]: $\rho = 0.446 \text{ g/cm}^3$, $E_L = 22.2 \text{ GPa}$, $E_R = 9.49 \text{ GPa}$, $E_T = 0.512 \text{ GPa}$, $\nu_{LR} = 0.37$, $\nu_{RT} = 0.43$, $\nu_{LT} = 0.47$, $G_{LR} = 0.238 \text{ GPa}$, $G_{RT} = 0.04 \text{ GPa}$, $G_{LT} = 0.238 \text{ GPa}$; where, ρ shows density, E Yong's modulus, ν Poisson's ratio, G shear modulus, L direction along grain, R direction across grain, T tangential direction, LR regularly grained plane, RT end grain plain, and LT flat-grained plain. This means that the bracing can be designed at will by controlling the physical values as well as in the case of no bracing. Further, the composite top board can be designed in the upper range of the curve of the wooden top board with bracing shown in Fig. 4 by making the above E values higher. Thus, a top board

having no corresponding characteristic in a wooden top board can be made using the composite.

Previous attempts to developed composite materials for use as instrument soundboards have been based on the concept that the sound of a wooden musical instrument should be reproduced by replicating the physical properties of wood. To further improve this concept, the results of the present study demonstrated the possibility of making remarkable top boards without wood construction using composite materials.

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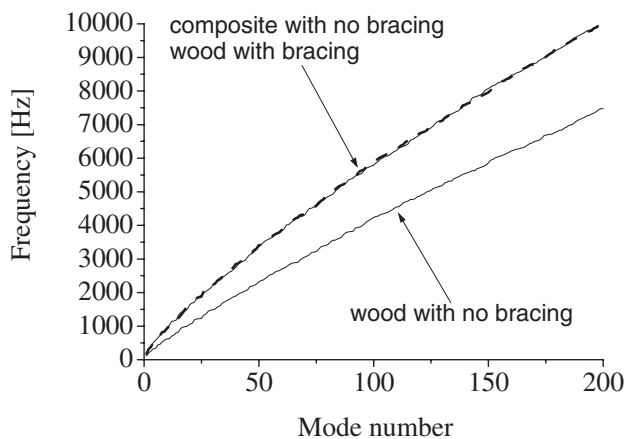


Fig. 4 Bracing effect and design of a composite top board with no bracing.

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