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EVALUATION OF STRAIN AND STRESSES STATES OF REINFORCED GUITAR NECK WITH FINITE ELEMENTS METHOD

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Abstract: *Many guitarists have found that guitar neck deforms due to tensions of the strings during the singing and the relaxation due to internal stress accumulated in the neck structure. This bending of the neck is a defect that affects the sound quality of the guitar. As a result, there are numerous methods of reinforcement of the neck with the metal rods which can be pre-tensioned or can be adjusted. The paper evaluated variants guitar neck reinforcement (rods of circular section, rectangular section, T section). The five alternatives were modeled and were determined the strain and stresses states of the guitar structure for different reinforcement bars applied in different areas of the neck of the guitar. It was found that both shape, material and position of bars from the fingerboard different and leads to smaller displacement of neck. The results may be useful to manufacturers of musical instruments.*
Keywords: *reinforced guitar neck, stress, finite element method, stiffness, strain*

1. INTRODUCTION

One of the most important stresses of mechanical engineering is bending produced both and shear forces bending moments. In case of mechanical structure of the guitar, guitar neck which can be considered a cantilever beam bending in the plastic domain conducting to fall upon quality acoustic musical instrument. The researchers focused on stiffening the neck by a reinforced system with metal rods, fixed or adjustable tension rods made from hardwood timber, steel, carbon fiber, glass fiber. Gordis (http://www.ukuleles.com/Technology/neck.html) conducted a study on the calculation of flexural strength of ukulele and guitar neck, causing the neutral axis of tension produced in the neck section. These rods have different sections and ways of handling. They are made of lightweight material that does not change the structure weight. They act as static: the position of the rods in cross section neutral axis position changes so that the balance of tension and compression stresses (Figure 1). From the mechanical point of view, most of the tension rod is adjustable by means of a screw-nut system (Figure 2) [1, 2].

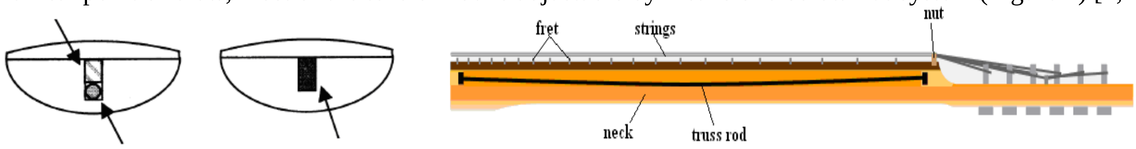


Figure 1. Transverse and longitudinal section of the neck of the guitar in the reinforced http://en.wikipedia.org/wiki/Truss_rod, http://www.warmoth.com/guitar/necks

Figure 2. Types of reinforcing rods neck (http://www.frets.com)

This paper aims to assess the effectiveness of the reinforcement system of the neck of the guitar from the point of view of the loads and displacements size during bending.

2. EVALUATION OF DEFLECTION CURVE OF GUITAR NECK USING FINITE ELEMENT ANALYSIS

The neck of the guitar is a cantilever beam used both for strength and ergonomic, aesthetic and functional. These bars are effective when the variation law of cross-sectional is optimal choose such that in all cross-sections maximum normal stresses are equal. Only at rest but loaded with forces / moments of strings tension, the guitar neck meets the criteria of a bar of equal resistance. The neck of the guitar is stressed by normal forces (N_i) of tensioned strings which generate a bending moment (M_b) and torques moment (M_t). Depending on the bridge height, bending moments have higher or lower value. Torques moment is produced by variation of intensity of normal force related to symmetrical longitudinal axe. In previous articles, it was presented an analytical calculus to determine the sectional efforts from guitar structure due to tune of guitar strings [3, 4]. Geometry of guitar was modeled in Abaqus taking into account the real dimensions of guitar and the main parts of them – guitar body, neck, fret board and frets (Figure 3). For meshing were used tetrahedron elements.

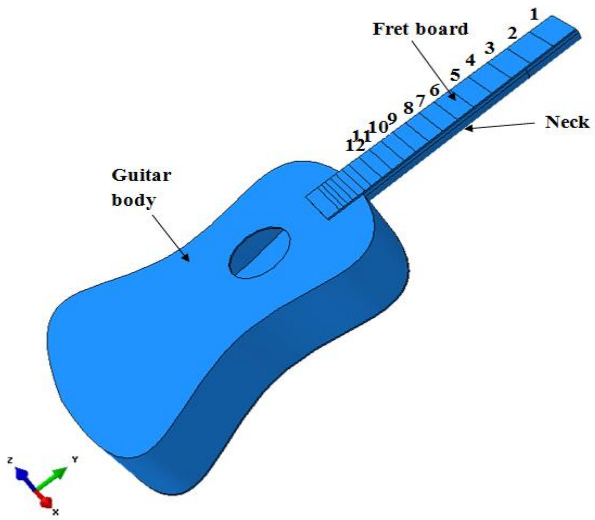


Figure 3. Main parts of guitar

The most important part of guitar in this study is neck which was reinforced successively with three types of rods from section point of view. Seven cases were analyzed: case 1 - neck without reinforcement system; case 2 – neck reinforced with rectangular rod; case 3 - neck reinforced with rectangular rod translated with 5 mm; case 4 - neck reinforced with T rod; case 5 - neck reinforced with T rod translated with 5 mm; case 6 - neck reinforced with circular rod; case 7 - neck reinforced with circular rod translated with 5 mm (Figure 4). The rod material was considered steel with elasticity modulus of $2x10^5$ MPa.

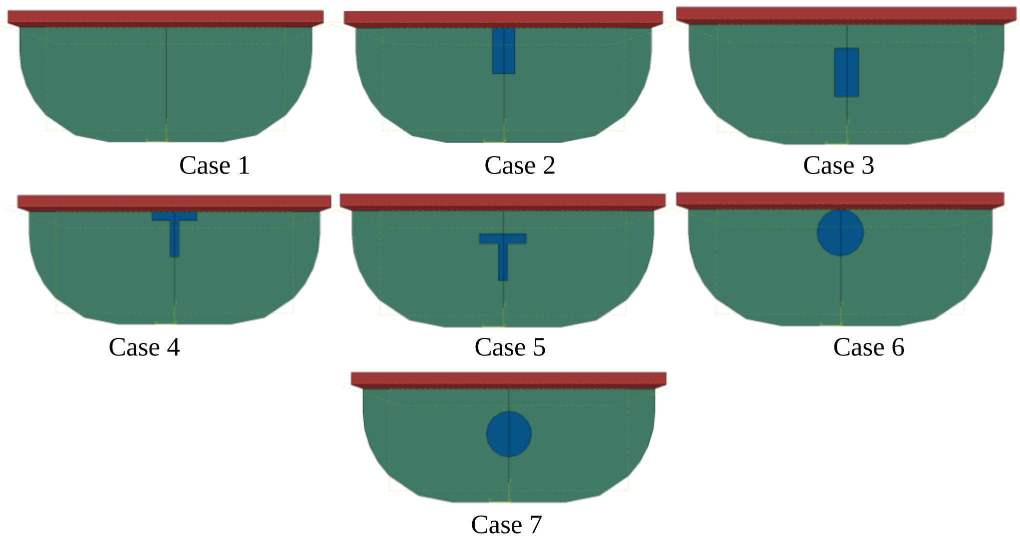


Figure 4. Reinforced system of guitar neck

In the preprocessing stage, there were introduced the specific parameters of the guitar neck and the guitar body. Table 1 summarizes the elastic characteristics of guitar components taken from literature [5, 6, 7].

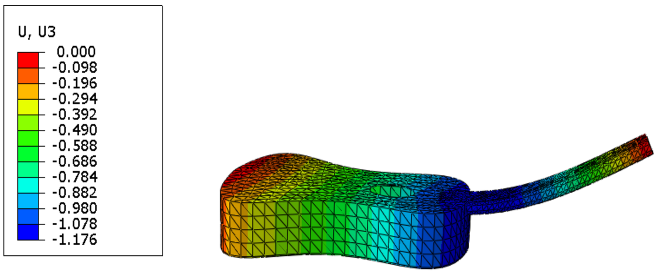
Table 1: Elastic characteristics of wood species used in guitar structure

Components	**Wood species**	**Modulus of Longitudinal Elasticity** ***E [MPa]***	**Modulus of Transversal Elasticity** ***G [MPa]***	**Poisson's Coefficient** ν
Neck	Beech *Fagus sylvatica*	E_L=14200 E_T= 1160 E_R= 2280	G_{LR}=1970 G_{LT}= 950 G_{RT}= 467	ν_{TR}=0,30; ν_{RT}=0,64 ν_{LT}=0,50; ν_{TL}=0,085 ν_{RL}=0,12; ν_{LR}=0,32
Fret board	Locust *Robinia pseudoacacia*	E_L =19900 E_T = 1650 E_R = 3040	G_{LR}=2100 G_{LT}= 980 G_{LR}= 530	ν_{TR}=0,31; ν_{RT}=0,66 ν_{LT}=0,63; ν_{TL}=0,090 ν_{RL}=0,14; ν_{LR}=0,40
Guitar Body	Spruce *(Picea abies (l.) Karst.)*	E_L =16225 E_T = 400 E_R = 700	G_{LR}= 650 G_{LT}= 416 G_{RT}= 347	ν_{TR}=0,25; ν_{RT}=0,42 ν_{LT}=0,33; ν_{TL}=0,013 ν_{RL}=0,028; ν_{LR}=0,40

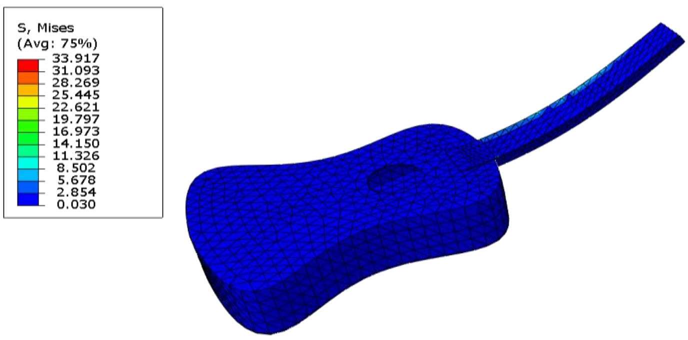
It was established the boundary conditions: the head of the neck was pin connected and the end of guitar body was fixed. It was successively applied a distributed forces of 0,1 MPa on each fret.

3. RESULTS AND DISCUSSION

After running the program with finite element analyses, the maximum stresses and strains values obtained when the structure was loaded on each fret, being processed into graphical variation. In Figure 5 is represented the displacement and stresses von Mises. The results in terms of maximum stresses and displacements for all types of stiffening system are presented in Table 2 and 3. It can be noticed that variation of static behavior of guitar neck depends on type of reinforcement and position of them in transversal section. Position of load on fretboard influences the tension of guitar neck, So, with increasing the distance between force and supports conduct to increasing the bending moment and stresses. Also, the type of reinforce bar lead to different behavior of guitar neck related to stresses. The most efficient stiffening bar is T shape (case 4 and 5). Minimum value of stress is obtained in case of simple neck – without reinforcement (case 1) and in case of rectangular shape of bar section displaced with 5 mm below fretboard (case 3).



a)



b)

Figure 5. Stress and strain of guitar: a) displacement; b) normal stress

Table 2: Maximum normal stresses obtained for load on each fret of guitar neck

	Fret 1	Fret 2	Fret 3	Fret 4	Fret 5	Fret 6	Fret 7	Fret 8	Fret 9	Fret 10	Fret 11	Fret 12
	Maximum normal streses σ [MPa]											
Case 1	13,82	22,59	23,15	26,69	27,61	32,89	31,01	31,1	36,39	32,02	26,82	19,51
Case 2	25,59	39,54	37,27	39,03	32,48	33,94	33,14	33,92	34,47	34,38	29,83	29,15
Case 3	6,7	10,99	11,33	13,11	13,19	13,85	13,75	13,93	13,88	13,88	14,24	11,12
Case 4	56,31	92,47	94,7	106,94	101,35	102,85	107,96	108,42	108,85	112,04	98,24	70,94
Case 5	51,04	83,84	86,5	98,13	92,91	94	97,74	102,89	100,1	97,13	84,46	63,37
Case 6	25,37	41,69	43,08	48,22	44,73	39,91	43,29	46,54	43,82	40,57	39,79	28,85
Case 7	25,85	42,94	43,6	50,07	47,39	52,42	50,62	49,88	53,78	53,25	44,37	31,83

Table 2: Maximum displacement obtained for load on each fret of guitar neck

	Fret 1	Fret 2	Fret 3	Fret 4	Fret 5	Fret 6	Fret 7	Fret 8	Fret 9	Fret 10	Fret 11	Fret 12
	Maximum displacement Δ [mm]											
Case 1	1,11	1,79	1,79	1,99	1,94	2,08	2,07	**2,11**	2,07	2	1,74	1,29
Case 2	0,5	0,81	0,79	0,86	0,83	0,87	0,85	0,86	0,83	0,79	0,69	0,51
Case 3	0,3	0,47	0,45	0,49	0,46	0,48	0,47	0,47	0,45	0,43	0,37	0,28
Case 4	0,7	1,05	1,04	1,14	1,1	1,17	1,16	1,17	1,14	1,1	0,96	0,71
Case 5	0,64	1,02	0,99	1,09	1,05	1,12	1,1	1,11	1,08	1,035	0,89	0,67
Case 6	0,73	1,15	1,14	1,26	1,22	1,29	1,28	1,29	1,26	1,22	1,06	0,79
Case 7	0,68	1,09	1,07	1,18	1,14	1,21	1,19	1,2	1,17	1,12	0,97	0,72

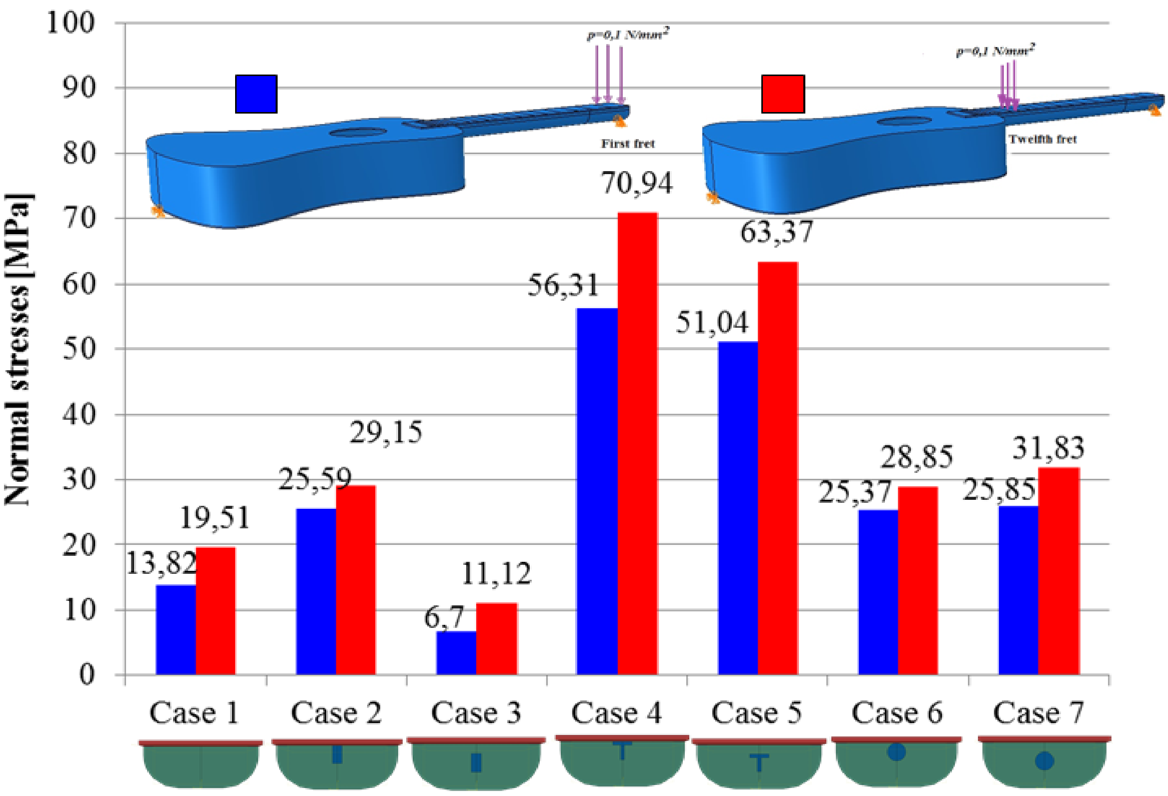


Figure 6. Variation of normal stresses with type of reinforcement and position of load on fretboard

Concerning of displacement variation, maximum values are obtained in case of simple guitar neck (case 1) which means that the neck is exposed to flexural bending and in time to residual displacements. This phenomenon leads to decreased acoustic quality of guitar. The lower values of displacement are recorded for rectangular shape of bar section translated with 5 mm below fret board. In this case (case 3), the position of load on fret board does not influence the size of flexural.

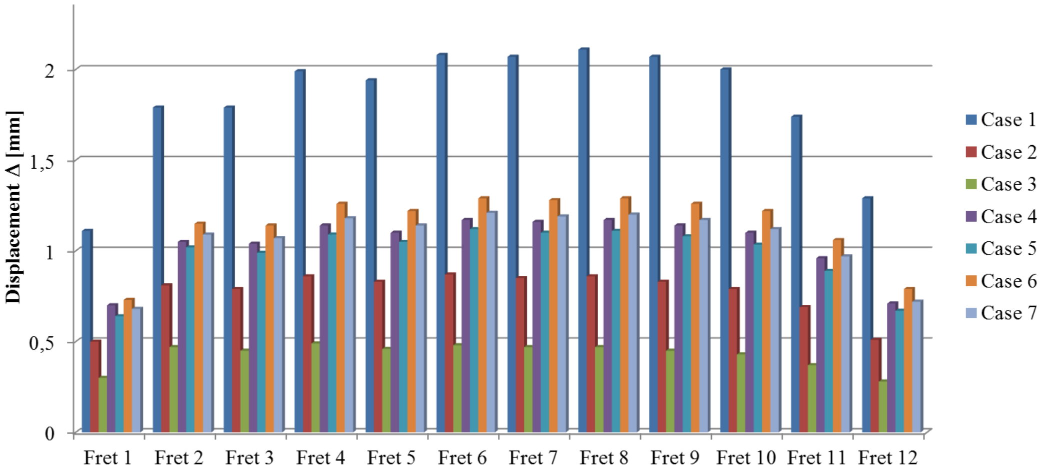


Figure 7. Variation of displacemen with type of reinforcement and position of load on fretboard

The reinforcement bars inserted in guitar neck modify the weight of guitar and thus the own frequency of guitar. So, it was analyzed the natural frequency and modal shapes for each type of reinforcement bar (Figure 8).

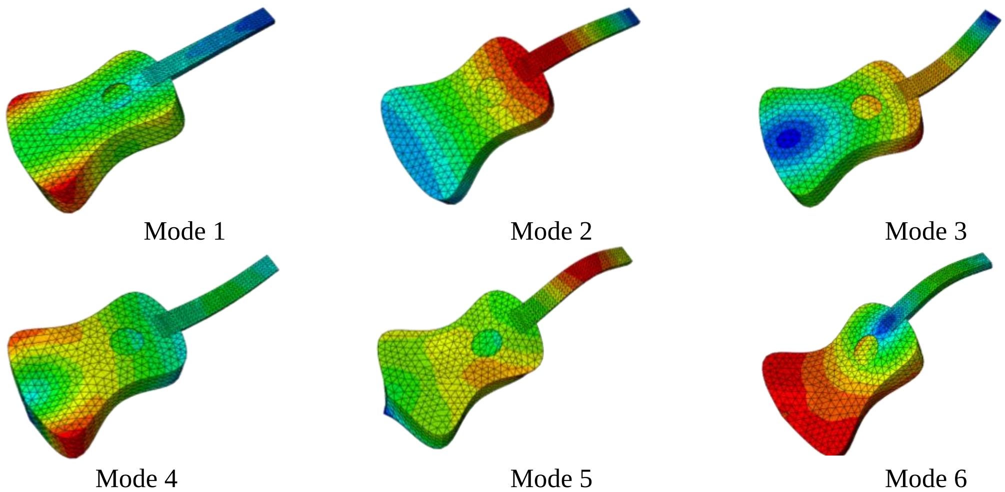


Figure 8. Modal shape of guitar

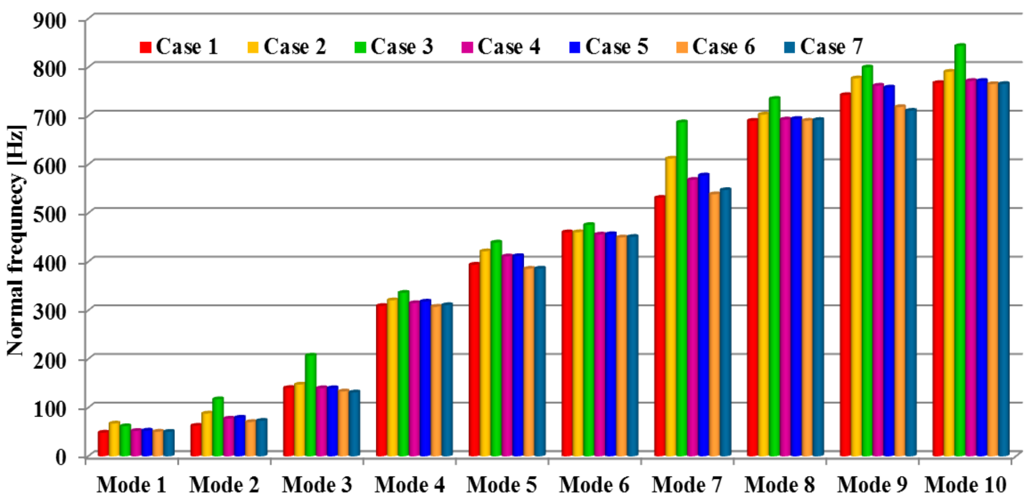


Figure 9. First eight natural frequencies for each case

The higher value of natural frequency is recorded in case of rectangular shape of bar section (case 2) and the lower value is obtained for not reinforced guitar neck. Similar values of natural frequency were obtained for the other types of cross section of bars (T and circular).

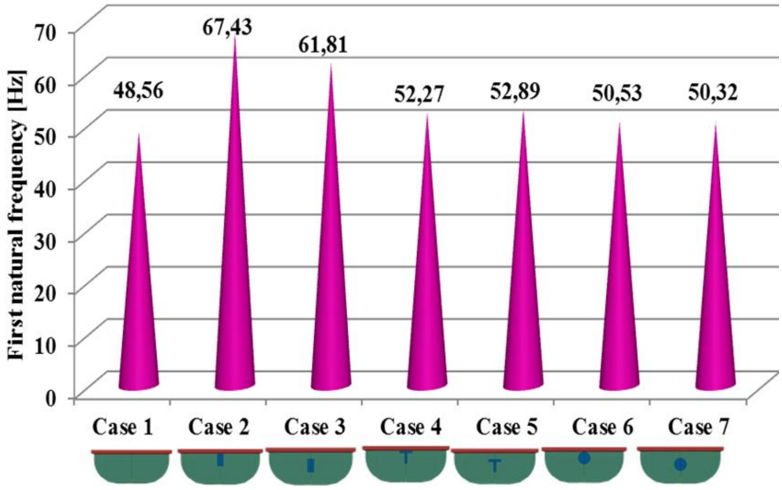


Figure 10. First natural frequencies for each case

4. CONCLUSION

In this paper was presented a numerical study of flexural bending with application of guitar neck which can be considered a cantilever beam. Due to dynamic loads during playing, the neck of guitar is subjected to flexural bending with residual displacement which leads to false tone. So, from mechanical point of view, is important to improve the rigidity of guitar neck using reinforce rods with different cross section shapes. It was analyzed seven cases and the conclusion is that regardless of type of cross section, the structure is stiffer compare to simple neck (case 1).

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