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SANDALYE ÇERÇEVESİNİN CATIA ILE SONLU ELEMANLAR ANALIZI

Murat AYDIN[1] Tuğba YILMAZ AYDIN[2]

[1] Süleyman Demirel Üniversitesi, Keçiborlu MYO, Mobilya ve Dekorasyon Programı, 32700, Isparta, TÜRKİYE
[2] Süleyman Demirel Üniversitesi, Orman Fak., Orman Endüstri Mühendisliği Bölümü, 32260, Isparta, TÜRKİYE
murataydin@sdu.edu.tr

Özet-Odun teknik olarak anizotropik bir malzemedir fakat genellikle transvers izotrop olarak modellenir. Ayrıca silindirik yapısı nedeni ile polar ortotropik bir yapısı vardır. Odunun Sonlu Elemanlar Analizi (SEA) için doğrusal elastik bölge, plastiklik, transvers izotropik plastiklik, Hill akma kıstası gibi birçok teori kullanılabilmektedir. Ahşap yapıların güvenli bir şekilde işlevlerini yerine getirebilmeleri için bileşenlerinin ve sistemin tümünün elastik bölge sınırları içerisinde davranması gereklidir. Bu çalışmada farklı enine kesit ölçülerindeki ön ve arka ayaklı kayın (*Fagus orientalis* L.) sandalye çerçevelerinin SE Analizi CATIA yazılımı ile gerçekleştirilmiştir. Elde edilen sonuçlar, enine kesit değerinin yük taşıma ve yükü tüm yapıya iletmede önemli olduğu ve bağlantı noktalarındaki gerilimi etkilediğini göstermiştir.

Anahtar Kelimeler- Sonlu Eleman Analizi, sandalye çerçevesi, kayın.

FINITE ELEMENT ANALYSIS OF CHAIR FRAMES USING CATIA

Abstract-Wood is technically anisotropic but usually modeled as transversely isotropic. Also it has polar orthotropic nature due to its cylindrical form. There are some theories used to FEA of wood such as linear elastic region, plasticity, transversely isotropic plasticity, hill yield criterion. Whole wooden system or its member's should behave in elastic region limits under loading to ensure the safe function of wooden structures. Finite Element Analysis (FEA) of chair frames, modelled using oriental beech (*Fagus orientalis* L.) material properties, which have different cross cut dimension of front and back legs were performed using CATIA software. Obtained results demonstrated that back legs are important to handle the applied load and transfer it to the whole structure and they have effects on stress at joints.

Key Words- Finite Element Analysis, chair frame, beech wood.

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1. INTRODUCTION

Computer usage and software aid to solve complex issues is getting more common with technological developments in almost all fields. Conceptual design is the beginning of manufacturing activity and followed by design, manufacturing, marketing and after sales services. Designing a consumer product depends of lots of parameters such as, market, demand, material, manufacturability, safe usage, product life, cost, human interaction, and etc. And manufacturing ways of goods changes according to material types. Elastic and plastic behavior of material are important design parameters to achieve safe and durable goods or structures. Computer Aided Analysis (CAA) is a numerical analysis method in order to understand and improve designs or constructions and CAA is used to ensure the safe functionality of structures. If the structures fails at analysis than design of them must be changed instead of beginning of production. Knowing elastic constants of material let us design structures that can be used safely at real life and under loading. Despite the wood is one of the oldest structural material used by human being there are lack of elastic constants of some wood species and it's important to model and analyze wooden structures or furniture constructions. Elastic constant consist of 12 parameters which are Young's moduli (E_L, E_R, E_T), shear modulus (G_{LR}, G_{LT}, G_{RT}) and Poisson ratio (μLR, μRL, μRT, μTR, μLT μTL). These parameters explain the elastic behavior of wood at a 3D macroscopic level [1-2-3-4].

Finite Element (FE) is numerical analysis method especially used to predict behavior of a product under real-like conditions. Stresses and displacement values of parts or assembled structures under loads (internal and external) are obtained to validate and approve the model or change it. Finite Element Analysis (FEA) is and CAA and it is used in almost all fields and there are lots of studies concerned with wood material as followings. Avez et al. [5] studied Finite Element Method (FEM) of inclined screwed timber-large gap-timber connections and modeled the wood as an orthotropic material. Gereke et al. [6] longitudinal tensile-shear samples studied using FEM and beech wood (*Fagus sylvatica* L) used for 3D modeling with orthotropic mechanical properties. Hong et al. [1] performed 3D-FEA using Douglas fir to determine compressive behavior.

Hofstetter and Gamstedt [7], Landis and Navi [8], Yoshihara [9-10-11-12], Yoshihara and Usuki [13], Isaksson et al. [14], Larsen and Ormarsson [15], and Yoshihara and Yoshinobu [16] performed FEA for wood. Casagrande et al. [17] developed a simplified numerical model for FEA of timber frame walls and CLT walls. Rossi et al. [18] studied numerical seismic analysis of light timber-frame buildings

Wood utilized as housing, heating, transportation and decoration. Technological developments effect usage of wood too and nowadays engineered wood products are getting more common than solid wood. Wood is a natural composite and it has orthotropic nature that means it has different mechanic properties through its principal axes (L, R and T). According to Sadd [19] wood has different elastic moduli in three principal axes and this type of materials is assumed as anisotropic. Due to this complex nature, working with wood, especially solid wood, is difficult than some materials.

Wood properties are almost recoverable when subjected to (constant or cyclical) loads in linear elastic region. When applied stress (loading) leads the material to plastic behavior region recovery is impossible and material can't return to its original shape. Thereby, linear elastic region is suitable for FEA and Mihailescu [20], Guan and Rodd [21-22] proved that it works fine in this range by using orthotropic model.

Yield point is the beginning of plasticity deformation and when considering the behavior of wood in plastic region, plasticity theory is involved in to perform analysis. In this region wood behaves non-linear and at the end of this region failure occurs at fracture point or ultimate stress. Nonlinear behavior of wood is studied by Moses [23], Kharouf [24], Oudjene and Khelifa [25] and Hering et al. [26] using plasticity theory. Beside this, there are some theories such as transversely isotropic plasticity (TIP) to perform analysis. Also, Hill yield criterion is a criterion for calculation of anisotropic plastic deformation using six material parameters

Oriental beech is native to the Balkans in the west, through Anatolia (Asia Minor), to the Caucasus, northern Iran and Crimea [27]. It is one of the most common hardwood species that used for chair manufacturing in Turkey and according to OGM, [28] it covers around 1.961.659,5 Ha. Due to these reasons, beech chair frames were modeled and analyzed using 3D orthotropic material properties in this study.

2. METHOD

Three dimensonal (3D) models of chair frames were created using Oriental beech (*Fagus orientalis* L.) wood and its 3D orthotropic material properties.

CATIA V5 R17 was used for Computer Aided Design (CAD) and Computer Aided Engineering (CAE) of the models. Twelve different chair frame models were created as seen in Figure 1 which shows the construction details of frames. Chair frames consist of three parts which are front and back legs and stretcher or seat frame as seen in Figure 1. Chair frames modeled without lower stretcher.

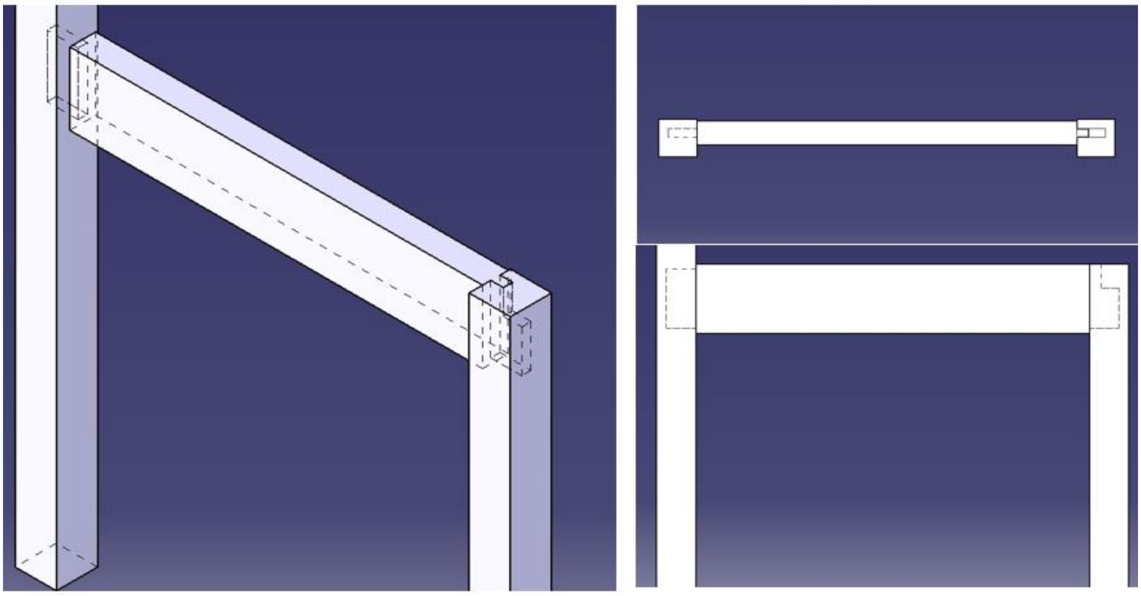

Figure 1. Construction details of chair frame.

Frames constructed using tenon and mortise joint as seen in Figure 1. Tenon has both cosmetic and structural shoulders. Also joint between front leg and stretcher was barefaced (haunched tenon). Mortise and tenon connection is one of the strongest woodworking joint but it’s not easy to prepare the parts. As seen in Figure 2, tenon and mortise were prepared as closer as possible to the side of the legs to provide longer tenon and mortise joint to ensure the maximum surface contact.

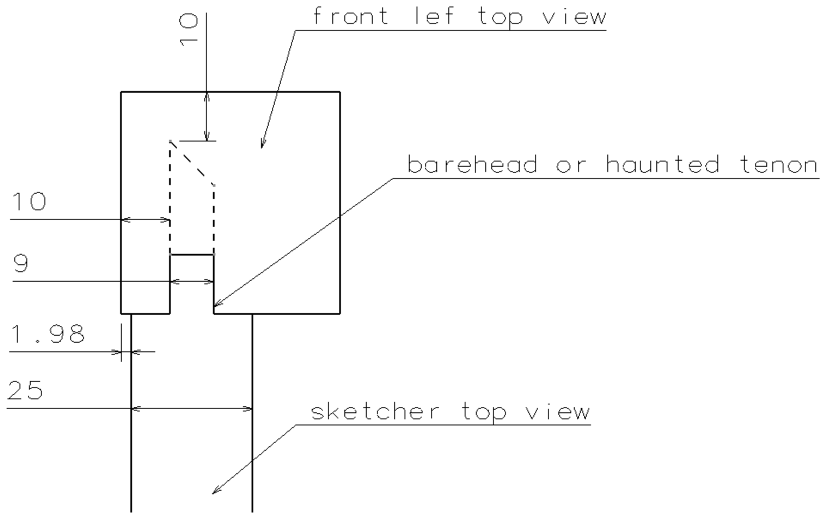

Figure 2. Tenon and mortise joint detail

Only front and back leg heights were constant and they were 450 and 850mm, respectively. Also dimension between legs were 400mm for all models. Yılmaz [29] evaluated chair frames constructed with beech wood and in this study approximately 45 (without lower stretcher), 39, 31, and 26mm and 31 (without lower stretcher), 27, 22, and 18mm cross cut dimensions (according to maximum moment) were calculated for front and back legs, respectively. From this point of view, 45, 40, 30, and 25mm were preferred to create cross cuts and prepared chair alternatives presented in Table 1.

Table 1. Modeled chair frame properties

	Dimensions (WxDxH in mm)			Mesh		Element Type		
Model Name	**Front leg**	**Back leg**	**Stretcher**	**Nodes**	**Elements**	**Spider**	**NSBAR**	**TE4**
45x45 (a)	45x45	45x45	70x25x470	508	1164	20	10	1134
45x40 (b)	45x45	40x40	70x25x465	506	1160	18	9	1133
45x30 (c)	45x45	30x30	70x25x455	435	961	20	10	931
45x25 (d)	45x45	25x25	70x25x450	437	961	18	9	934
40x45 (e)	40x40	45x45	70x25x465	501	1144	18	9	1117
40x40 (f)	40x40	40x40	70x25x460	502	1150	18	9	1123
40x30 (g)	40x40	30x30	70x25x450	427	943	16	8	919
40x25 (h)	40x40	25x25	70x25x445	484	1137	18	9	1110
30x45 (i)	30x30	45x45	70x25x455	511	1178	18	9	1151
30x40 (j)	30x30	40x40	70x25x450	511	1186	16	8	1162
30x30 (k)	30x30	30x30	70x25x440	480	1141	16	8	1117
30x25 (l)	30x30	25x25	70x25x435	487	1149	18	9	1122

Legs and stretcher were created separately using part design module. Parts directions (X, Y, and Z) were in line with wood directions and they were R, T and L directions. These 3D parts assembled together using assembly design module. In this stage coincidence and contact constraints were used to assemble the chair frames or product. These constraints are essential for structural analysis and connection properties can be defined using them. In this study, rigid connections created between mortise and tenon joints. OCTREE tetrahedron mesh with linear element type chosen to define material properties.

Required structural properties of material for FEA varies according to lots of parameters such as used software, anisotropy, isotropy, orthotropic and etc. In this study 3D orthotropic material properties [30-31-32] used to perform structural analysis as seen in Table 2.

Table 2. Required structural properties of 3D orthotropic material for FEA in CATIA.

Parameters	Unit	Direction or planes and values		
Young Modulus	(N/m^2)	Longitudinal	Transverse	Normal
		1,305e+010	9,57e+008	1,829e+009
Poisson ratios	-	XY (RT)	XZ (RL)	YZ (TL)
		0,565	0,064	0,449
Shear modulus	(N/m^2)	XY (RT)	XZ (RL)	YZ (TL)
		4,3e+008	1,23e+009	8,87e+008
Density	(kg/m^3)	700		
Thermal expansion	(K/deg)	Longitudinal	Transverse	Normal
		-	-	-
Tensile stress	(N/m^2)	Longitudinal	Transverse	Normal
		5,2e+007	8e+006	-
Compressive stress	(N/m^2)	Longitudinal	Transverse	Normal
		5,2e+007	8e+006	-
Shear stress limit	(N/m^2)	XY (RT)	XZ (RL)	YZ (TL)
		4e+006	1,2e+007	1,1e+007

FEA can be performed using linear or non-linear behavior. In this study linear structural analysis performed using generative structural analysis module due to lack of non-linear structural analysis module, but to obtained real-like structure behavior non-linear analysis should be performed.

Chair frames analyzed by diagonally applied 80kg (785N) distributed force through front leg to fixed back leg as seen in Figure 4. TS 9215:2005 [33] standard explains how chairs are diagonally tested. Deformed mesh, Von Mises stress, translational displacement vector and stress principal tensor values were obtained as static case solutions at the end of analysis and these results were presented as figures.

3. FINDINGS

Results seen in figure 3 to 8 represent the behavior of chair frames under 80kg load when leg cross cut dimensions changed, respectively. In Figure 3 and 4, front leg cross cut dimensions of chair were constant (30x30mm) while back leg were 25x25, 30x30, 40x40, and 45x45mm. Total translational displacements of model l and k were 113 and 77.3mm, respectively.

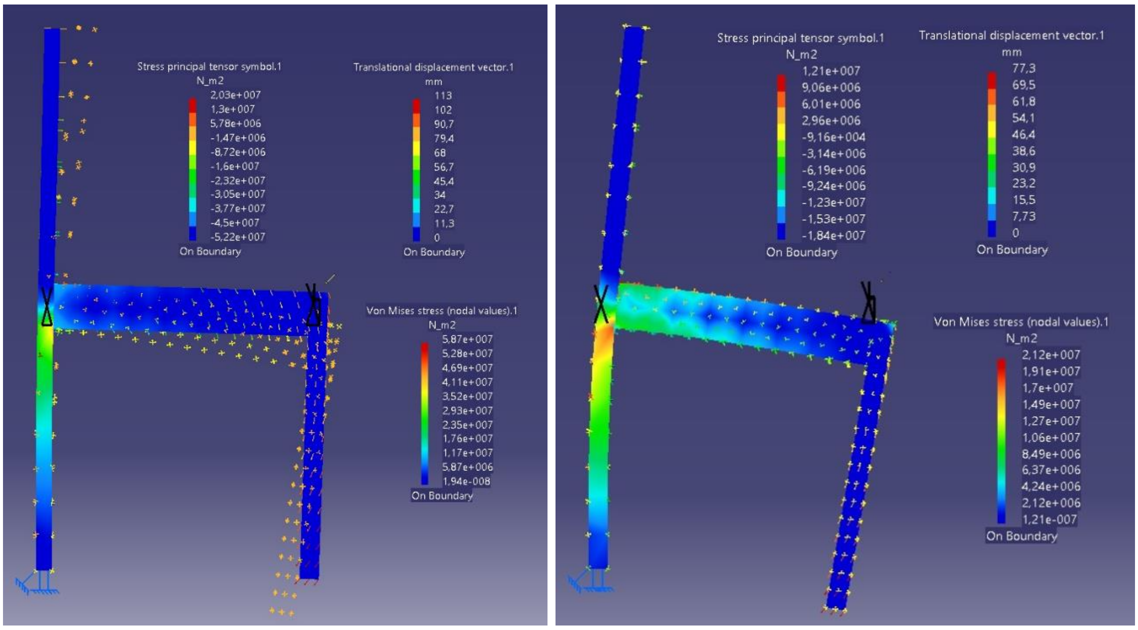

Figure 3. FEA results of model l (left) and k (right) chair frames.

Total translational displacements of model j and i were 52.5 and 46.3mm, respectively as seen in Figure 4. When compared with the results of model l and k, it’s obvious that there is big differences between them.

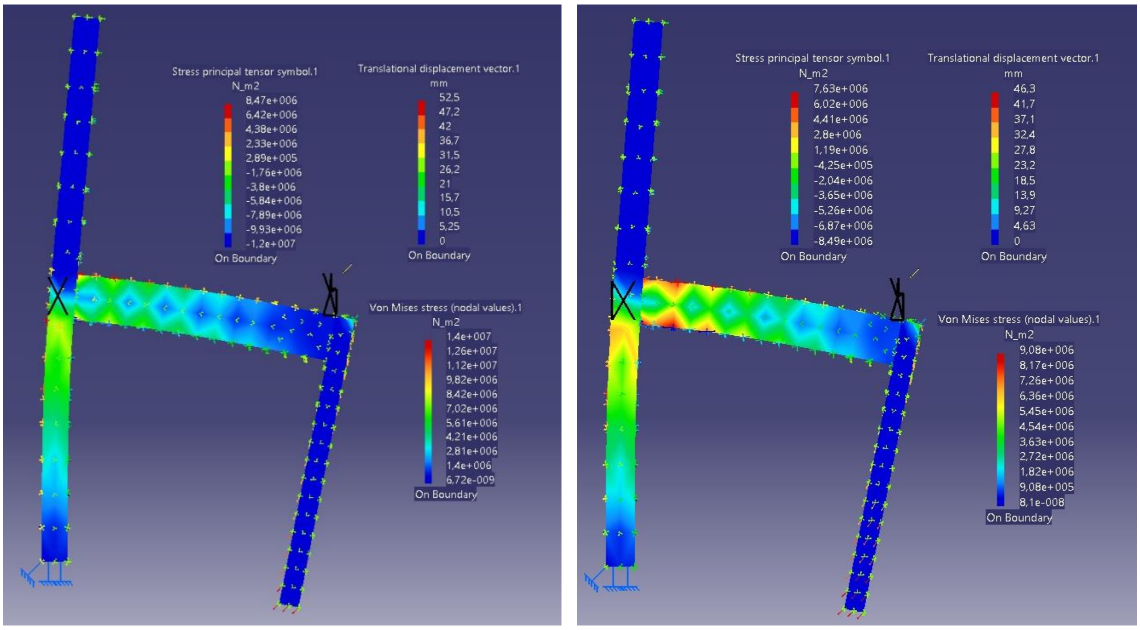

Figure 4. FEA results of model j (left) and k (right) chair frames.

In Figure 5 and 6, front leg cross cut dimensions of chair were constant (40x40mm) while back leg were 25x25, 30x30, 40x40, and 45x45mm. Total translational displacements of model h and g were 120 and 78.3mm, respectively as seen in Figure 5.

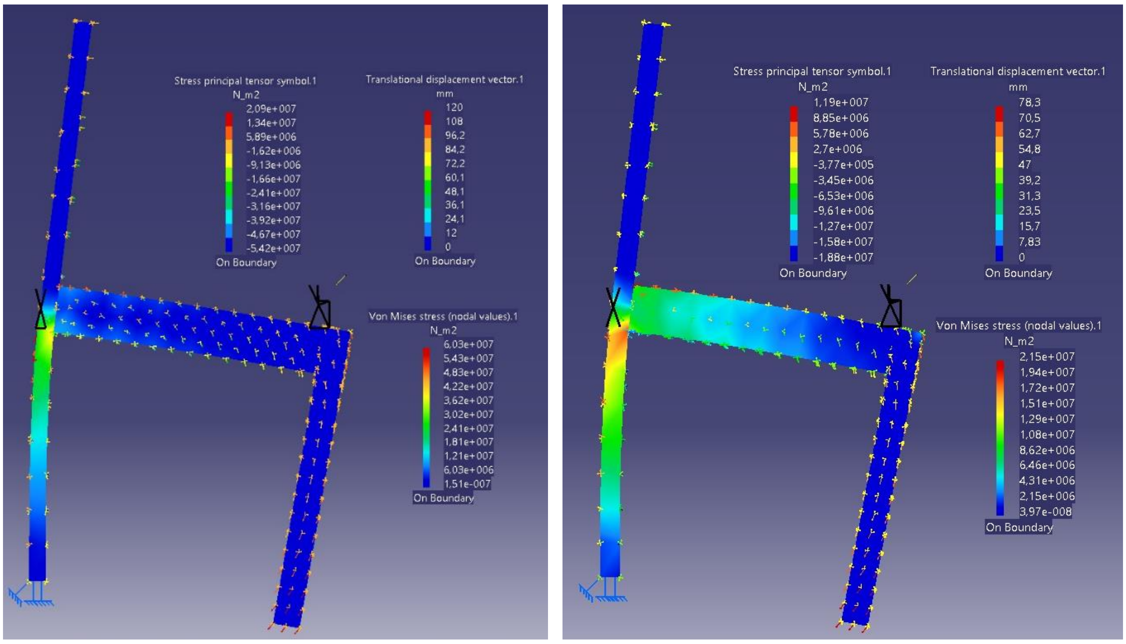

Figure 5. FEA results of model h (left) and g (right) chair frames.

Total translational displacements of model f and e were 55.3 and 49.1mm, respectively as seen in Figure 6. When compared with the results of model h and g, it’s obvious that there is big differences between them.

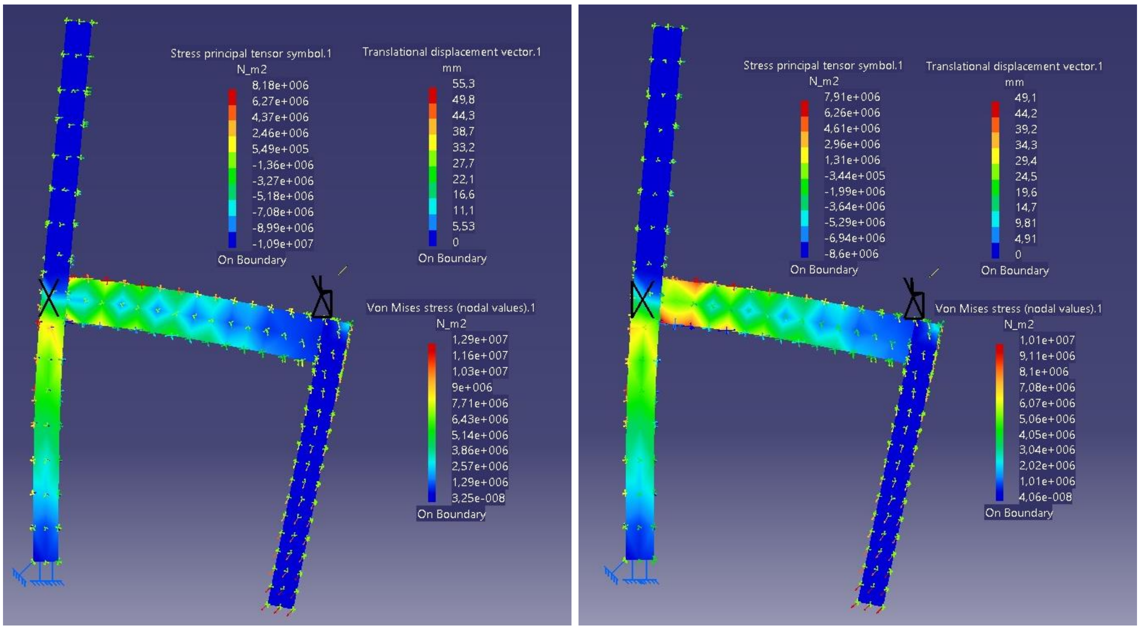

Figure 6. FEA results of model f (left) and e (right) chair frames.

In Figure 7 and 8, front leg cross cut dimensions of chair were constant (45x45mm) while back leg were 25x25, 30x30, 40x40, and 45x45mm. Total translational displacements of model d and c were 119 and 80.8mm, respectively as seen in Figure 7.

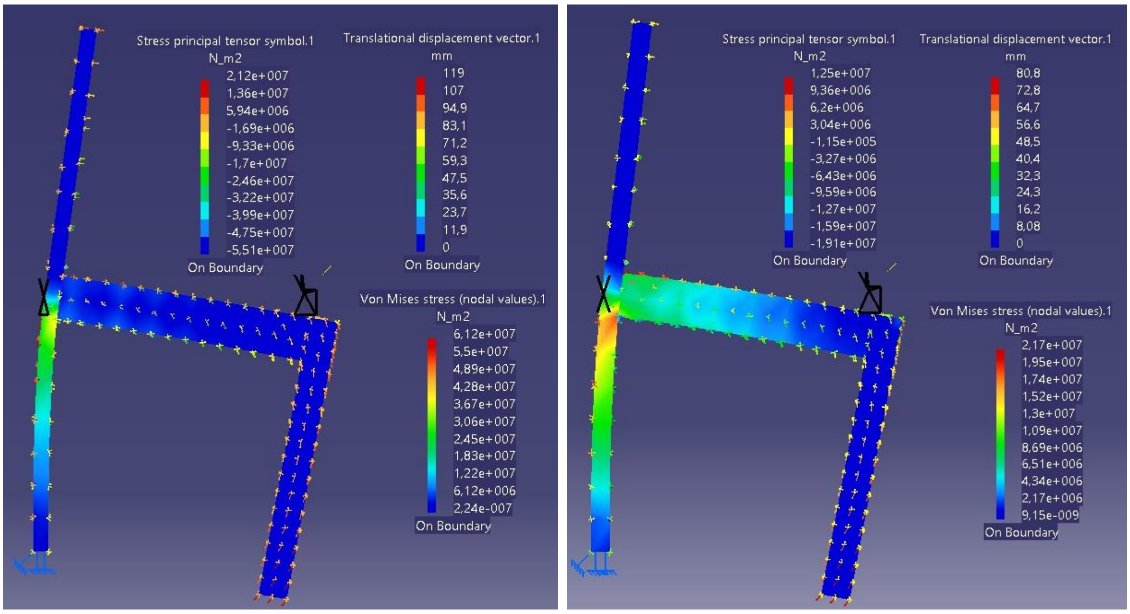

Figure 7. FEA results of model d (left) and c (right) chair frames.

Total translational displacements of model b and c were 57.6 and 49mm, respectively as seen in Figure 8. When compared with the results of model h and g, it’s obvious that there is big differences between them.

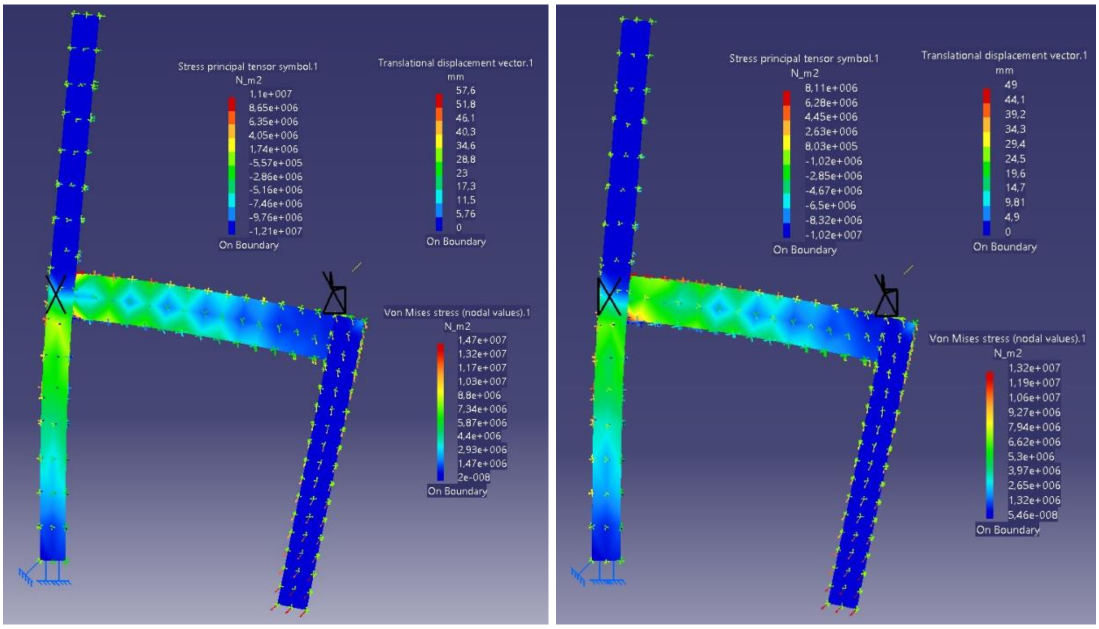

Figure 8. FEA results of model b (left) and a (right) chair frames.

4. CONCULUSION AND DISCUSSION

FEA of wooden parts or assemblies is getting difficult due to complex natural structure of wood. Existence and share of early and late wood in a wooden member causes an inhomogeneous model due to density differences. In this study this aspect was neglected. Hong et al. [1] stated that calculations are getting more complex when complex structure of wood (microscopic and macroscopic levels) taken into consideration and therefore high computer capacities needed. And, annual rings' effect on deformation is one of the complexities while modeling the wood as 3D FE at macroscopic level. Also construction way of wooden structures, for example joints with adhesive, effects the results of FEA. Adhesive usage requires an interface zone between contacting surfaces while performing FEA and according to Gereke et al. [6] an interface zone integrated with adhesive should be implemented both side of the contacting surfaces to assess the effect of adhesive. But, penetration depth of adhesive may not be accurate.

When working with wood material, numerical simulations getting sensitive due to some parameters such as adhesive type and its penetration behavior depends on wood structure, wood (type, annual ring, grain and fiber orientation), interface zone if existence, material properties according to isotropic, anisotropic or orthotropic assessment, construction type. Also macroscopic and microscopic level of wood structure may affect the results.

FEA of wooden structures has been studied using various softwares till now. In this study, CATIA used to analyze FE Models. FE Models analyzed under constant load of 80kg. Linear structural analysis performed in this study. But to better understand the real behavior of wooden members or structures, 2D or 3D orthotropic material properties must be defined and used to perform non-linear analysis. Non-linear analysis is much more complex process than linear one and it is not so easy to perform it and read its results. Considering a problem as linear instead of nonlinear makes analysis easier but results may not represent the solution of problem in the most correct way due to stress and strain relation or load deformation formation. When obtained graphs of FEA are evaluated together, it can be said that back legs can handle the applied load and transfer it to the whole structure if cross sectional dimension rises. This does not only minimize the stress of joints but also does displacement. As a result, it can be said that CATIA allow users to perform CAD, CAE or CAA application in a few step without any additional software.

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