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Investigation of The Effect of Knitting Row on Vibration Structure for A Wide Chimney Made With Brick Bar

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Abstract

Building systems have unique structural behaviour. In addition to the obvious material properties used in the formation of this behaviour, the geometric shape is also of great importance. In this study, the mechanical effects on the chimney-shaped structure built with bar bricks for product storage were investigated under compression and vibration conditions. Finite element analysis was used as a research method. Solid bar bricks and cement with standard specifications were used as the intermediate filling material for the construction system, which was formed in a wide circular array and short knitting height. Considering the ideal behaviour of the materials, a fully elastic solution was made. As a result of the examination, the effect of the knitting order on the natural frequency was found to be low, as the reason for this, it was seen that the geometric structure exhibited a very tough behaviour against deformation. The stress concentration was observed at the fillings between the bricks laid in the same layer. The dimensionless deformation at natural frequencies was 1.4 times the diameter of the chimney. The knitting order affected stress values and symmetrical distribution formed in the brick. The results were discussed over the findings.

1. Introduction

Bricks, briquettes, and stone blocks occur at the base of the building system used to create a closed zone. By combining these building elements at the desired level, a single large structure is created. The mechanical behaviour of the created structure is unique to itself and mostly depends on the material, the geometry and applied boundary conditions. In these structures, which have been used for a long time, different types of materials, joining arrangements, and spacer-filling materials have been used over time, and development studies are continuing. The behaviour of chimney brick structures has been studied in the literature for various loading conditions. Harvest warehouses (one of the chimney brick structures) [1], where agricultural products are stored, especially in farm regions, are made of metallic or brick structures and have a service life of 30 to 40 years. The warehouses [1-2] with a height-width ratio of around 3 can be shorter or longer. Most of the warehouses [3] are open-topped structures. For the self-protection of the structure, mechanical loading conditions and mechanical characteristics are examined and some cases are emphasized. Pande et al. [4] investigated the behaviour of brick and cement mortar under axial loading at different elastic modulus for knitted walls and expressed the results according to the equivalent material approach. The cement mortar used exhibited homogeneous orthorhombic elastic material behaviour. Magenes and Calvi [5] investigated the strength, deformation, and strain energy behaviour of a knitting wall under seismic conditions and developed simplified strength formulas obtained from some experimental and numerical results. They stated that the shear formations have dominated the collapse of the knitting walls in dynamic loading, and as a result, they defined a new equation for the slip that caused a fracture. Kaushik et al. [6] investigated the stress-strain behaviour by conducting axial compression tests for a wall built with solid clay bricks and mortar. They gained a non-linear stress-strain diagram, and six important control points were marked in that chart. Anthoine et al. [7] investigated the seismic behaviour for knitting walls experimentally and numerically and

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determined that the height/width ratio and vertical stress affect the seismic behaviour. Valluzzi et al. [8] defined three different problems in the masonry wall where they use fiber reinforcements: crushing the wall, separating the fibers and breaking the mortar by the slide along the joint. They have seen that the bond between the fiber plates and the wall was effective in strength and the used fiber reinforcement increased the strength and ductility. Priestley and Bridgeman [9] used reinforcement panels to prevent the collapse of knitting walls in seismic conditions and found that properly positioned horizontal steels suppressed all shear loads and increased the strength. Alforno et al. [10] observed different structural stiffness and reaction forces according to different brick patterns in the numerical analyses of masonry vaults. Srinithya et al. [11] conducted a wall-strengthening study focused on static and free vibration analysis. They investigated the effect of parametric properties with the finite element method and found that the toughness value increased by %43 and the deformation value decreased by %30.

Due to the limited number of studies in the literature and the lack of a detailed description of the physical properties of the chimney mesh structure, static and vibration analyzes were carried out for the brick masonry formed in the chimney structure.

2. Numerical Model

A basic model was created to examine the chimney structure formed by brickwork. The geometric structure was shown in Fig. 1. Using the chimney geometry in Fig. 1, the finite element model was created and examined. The brick chimney layers were stacked ten floors on top of each other. The angle of placement in the overlapping of chimney brick layers was expressed as (α°). The chimney structures prepared for different α values were shown in Fig. 2.

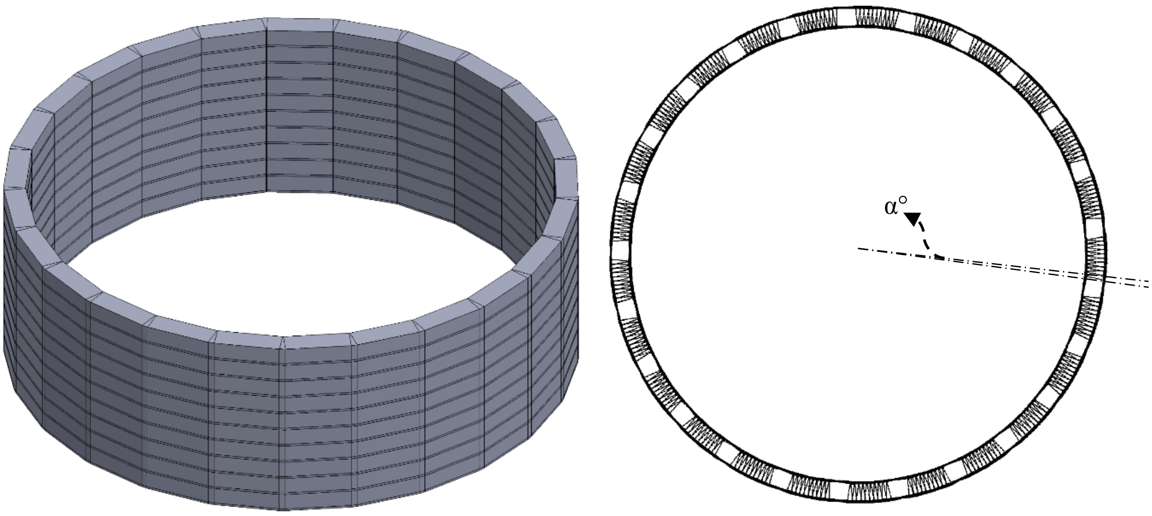

Figure 1. Isometric view of a flat knit brick chimney and a top view showing the different knitting order (α°).

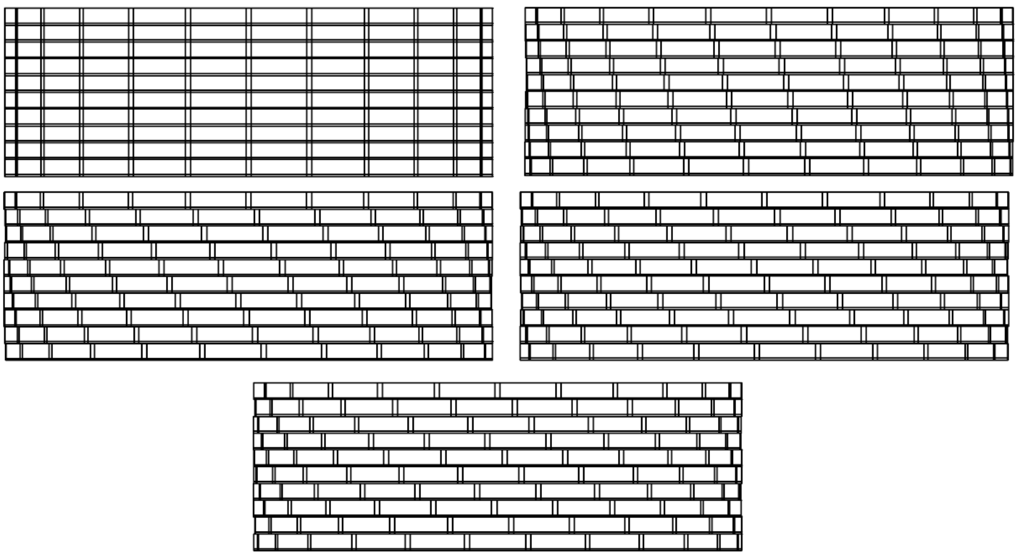

Figure 2. Different knitting rows of brick chimney layers.

Each brick has a length of 150 mm, a width of 50 mm, and a height of 40 mm. A chimney layer was formed using 25 bricks on a circular path having a radius of 625 mm. In the formation of the brick chimney, cement mortar was added between the bricks in the chimney layer and between the layers. Cement mortar of 5 mm thickness was used between layers and all mortar structures were bonded in contact definition. Brick material has a density of 1730 kg/m^3, Young's Modulus of 3.865 GPa, and Poisson's ratio of 0.094. Cement mortar has a density of 2300 kg/m^3, Young's Modulus of 30 GPa, and Poisson's ratio of 0.18. The gravity effect was neglected because the structure included a low aspect ratio. For the investigations, fixed boundary conditions were applied at the bottom surface of all chimney models. The first six modes were analysed for the modal analysis. The static stress analyses were applied with applying 1 MPa compression pressure to the upper surface of the chimney models. Linear elastic material behavior [12] was used in the analyses as similar to concrete silo analyses in the literature. According to defined linear elastic isotropic material properties, the stresses were given as Von-Mises stresses. The used Von-Mises stress was expressed in Eq. 1. The stresses on the right-hand side of the equation were the principal stresses. In Eq. 2, the general equation of motion was expressed.

$$\sigma_{VM} = \sqrt{\frac{(\sigma_1-\sigma_2)^2+(\sigma_2-\sigma_3)^2+(\sigma_3-\sigma_1)^2}{2}} \quad (1)$$

$$[M]\{\ddot{u}\} + [C]\{\dot{u}\} + \lfloor K \rfloor\{u\} = \{f(t)\} \quad (2)$$

It is expressed as $[M]$=mass, $[C]$=damping, $[K]$=stiffness, $\{\ddot{u}\}$=acceleration, $\{\dot{u}\}$=velocity, $\{u\}$=displacement, $f(t)$=load in the equation. Loading was not given in the modal analysis and therefore $f(t)$=0. The common properties of concrete [13] include low energy loss factor and damping coefficient in harmonic motion. Since it is [14] not reinforced with any damping effect enhancing mortar, its damping effect has been neglected; $[C]$=0. Thus, the vibration energy in the system returns from boundary conditions without any loss (heat or etc.). As a result the above equation for modal analysis;

$$[M]\{\ddot{u}\} + \lfloor K \rfloor\{u\} = 0 \quad (3)$$

It was assumed that each finite element made harmonic motion in the solution of the equation.

3. Result and Discussion

For the finite element model to be used, first of all, the effect of the number of finite elements on the results was investigated. Although absolute deformation definition and results were not important in modal analysis, it was used to show the effect of the number of elements and the results are shown in Fig. 3. As the number of elements reached a certain number, a stable deformation value was observed in the results. Approximately 35,000 finite elements were used in the study. In the stable results given by the finite elements created, the aspect ratio of the finite elements approached one. The average aspect ratio of the elements was 1.25.

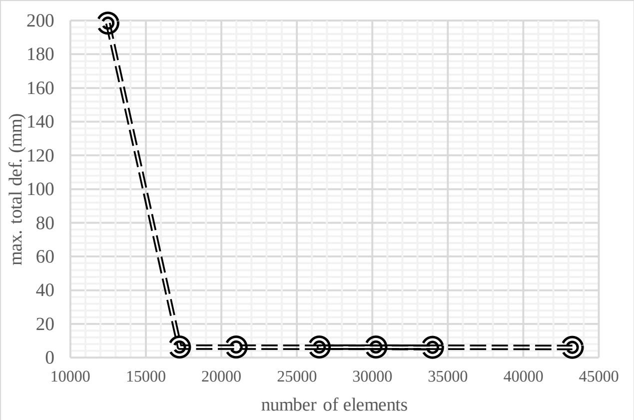

Figure 3. According to the number of elements used variation of the maximum total deformation resulting from mode 1 for α=0°

The natural frequencies of the chimney models of different knitting orders were given in Table 1. Due to the geometric structure of the system and the materials used, it was observed that the frequency difference between the modes was low.

Table 1. Natural frequencies (Hz) occurring at different α values

	α=0°	*α=1°*	*α=2°*	*α=3°*	*α=4°*
mod I	250.8	250.9	248.7	259.6	247.3
mod II	252.1	251.0	249.0	259.9	247.6
mod III	280.8	280.5	278.7	282.1	277.3
mod IV	281.3	280.5	278.9	282.6	277.4
mod V	291.3	292.5	290.8	302.3	290.0
mod VI	293.1	292.6	291.3	318.0	290.6

Natural frequencies and deformed shape of the brick chimney for different modes were shown in Fig. 4. As the geometry of the object has a short length and a large base size, bending and accordingly tension-compression situations have occurred rather than torsion. Modes were formed in ordered pairs. The mod I and II have the same modal deformation response. This condition was observed between mod III and IV, and also mod V and VI.

Frequencies were higher in chimney geometry rather than in similar samples in literature analyses. For example, a natural frequency of around 80 Hz was obtained on a flat wall built around a port [15]. In Fig. 5, the frequency response of the upper surface of the chimney was shown as dimensionless deformation in order to show this situation in more detail. The deformation amplitude in the modes was obtained as 1.4 times the circular pattern of the chimney. The fact that the dimensionless deformations of different knitting rows were the same, was due to the fact that the material used and the circular chimney size were the same. The same deformation location was not observed in some modes having the same frequency.

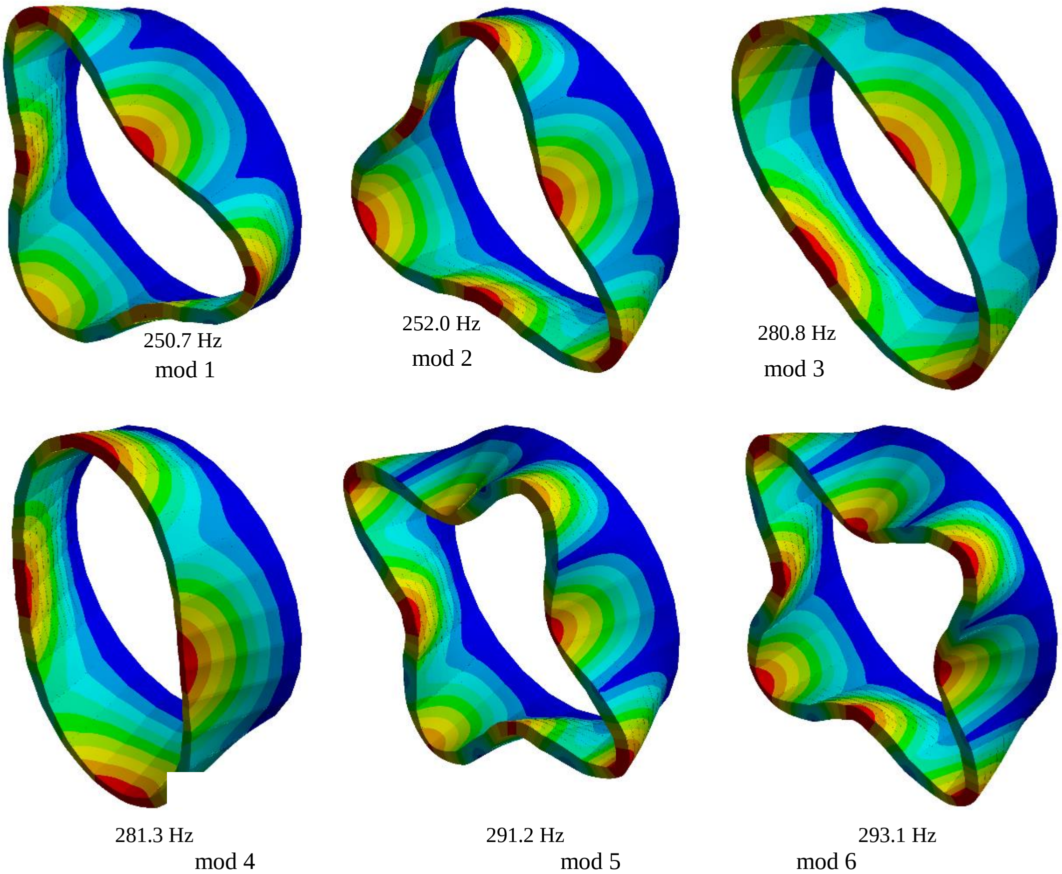

Figure 4. Frequency (Hz) and deformation structures resulting from the first 6 modes for α=0°

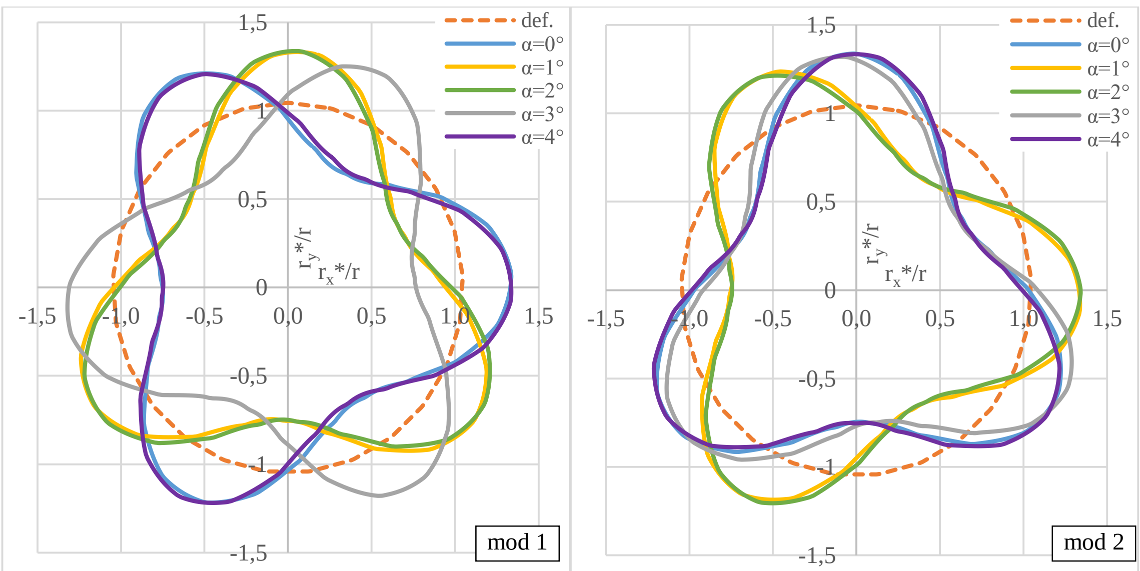

Figure 5. The deformation structure formed by different modes in the circle line on the upper chimney surface

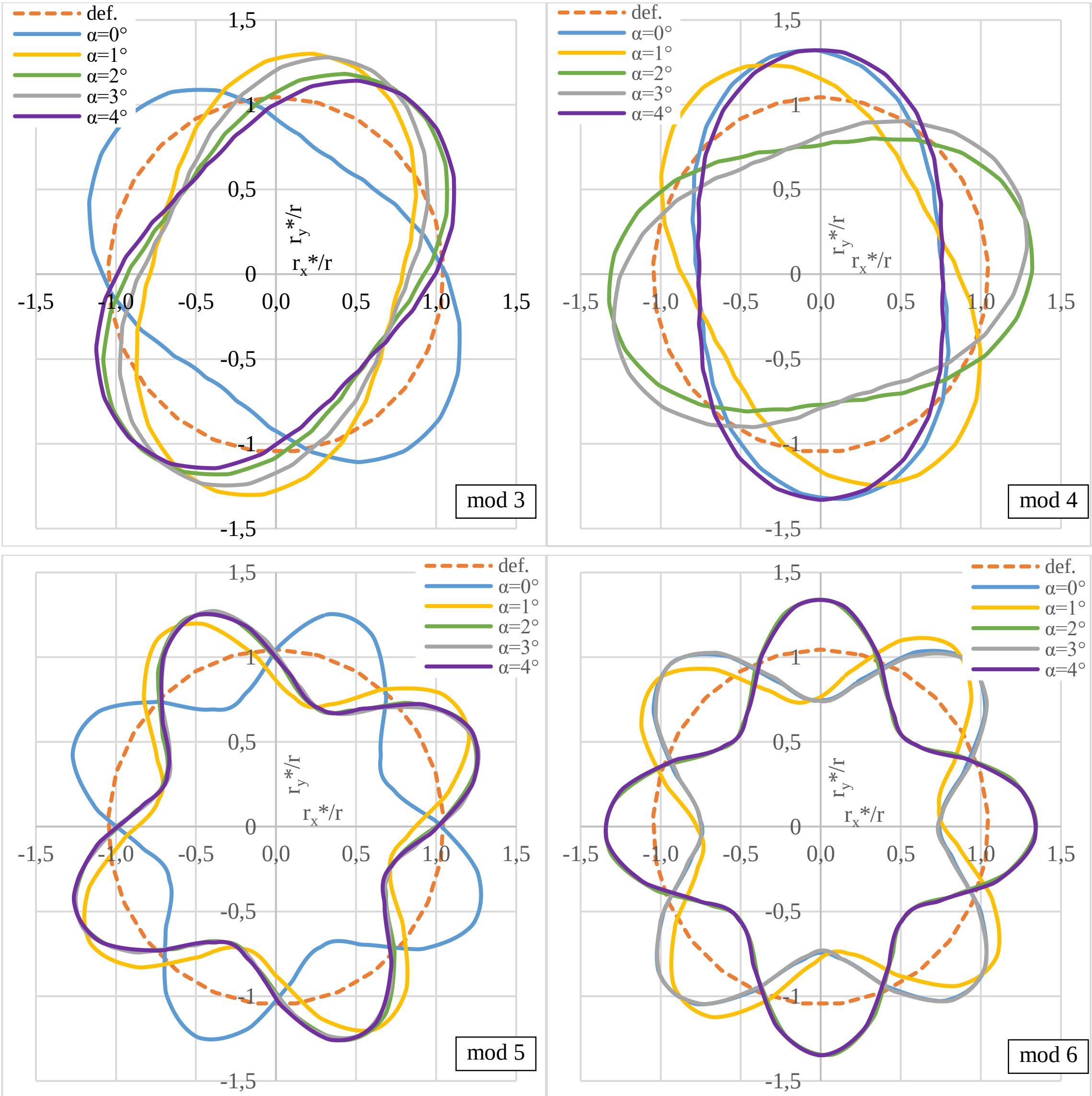

Figure 5. (Cont.) The deformation structure formed by different modes in the circle line on the upper chimney surface

In Fig. 6, the stresses in the chimney for different knitting rows as a result of the static compression were shown. Stress concentration locations were observed in the fillings between the bricks in the same layer. When the knitting order was changed, the stresses increased. In the case of the α=1° condition, the stresses in the fillings in the same layer were high and occurred in the form of a ladder row. However, stress concentrations on the brick were dispersed and of low value. Low stress near brick edges and high stress in fills showed irregularity in α=2° and α=3° results. As a result of α=4°, there were high local stresses occurred. In particular, it was observed that the filling between the bricks in the same layer had high stresses. The stresses of the brick were shown in the middle layer of the chimney profile in Fig. 7. The stresses in the bricks were lower than the stresses on the chimney. During different chimney knitting, the stresses and the symmetrical formation locations in the stress distribution have changed. The stress intensities formed at the brick corners shifted towards the brick edges in the cases of α=3° and α=4°.

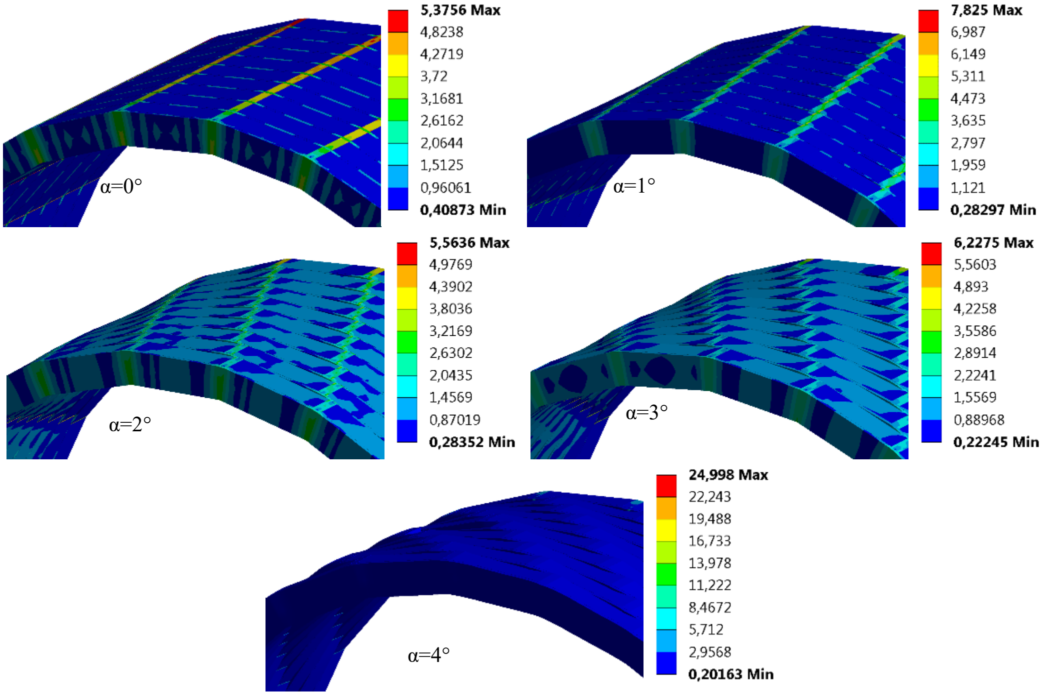

Figure 6. Von-Mises stresses (MPa) occurring in the chimney structure at different knitting rows

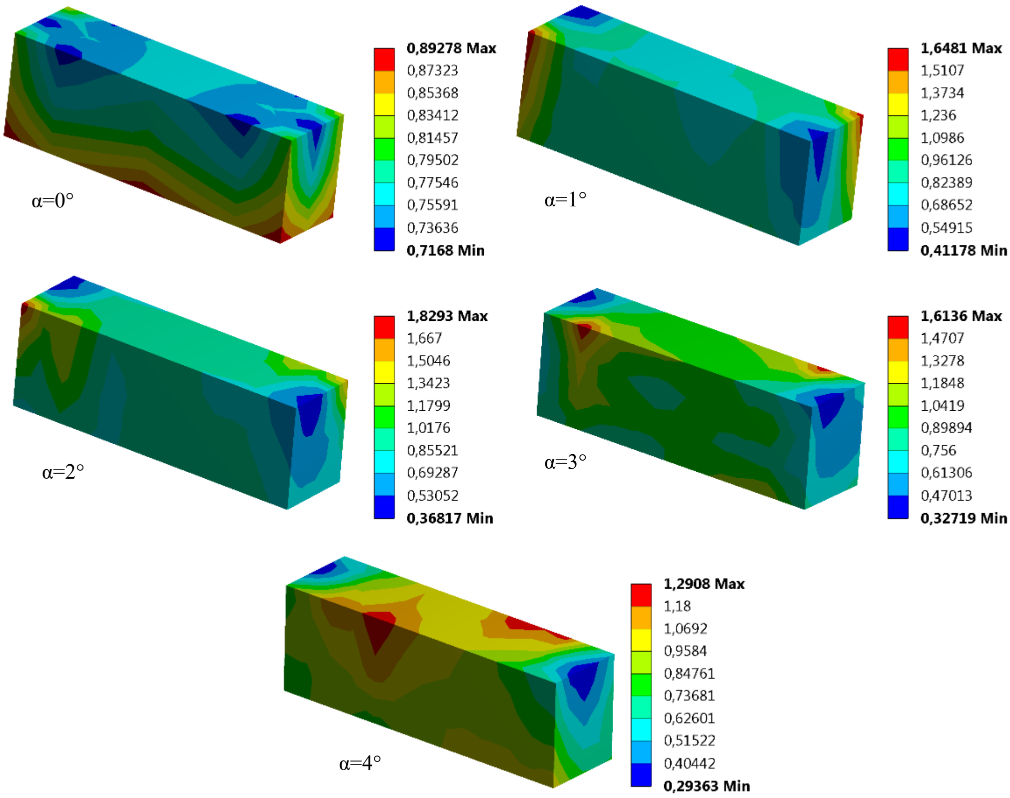

Figure 7. Von-Mises stresses (MPa) on a brick with chimney structural element at different lattice angles

4. Evaluation

In this study, the modal and static compression analyses of a layered chimney built with bar bricks with different knitting orders were numerically investigated. As a result of geometric irregularity, different stress and modal behaviours were obtained. If the findings are to be expressed item by item;

- Natural frequencies of chimneys with different knitting orders were observed between 250-290 Hz.
- The frequency difference between the modes was small and indicated the toughness of this structure to deformation.
- Knitting order differences have little effect on natural frequency.
- It is appropriate to use α=2° knitting row as an alternative to the plain knitting order.
- The stresses were concentrated in the fillings located between the bricks in the same layer.
- In the cases of α=3° and α=4°, the stresses occurring in the brick corners shifted toward the edges. This condition can reduce the breakage that may occur in the brick corners.

Declaration of Ethical Standards

The author of this article declares that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

Conflict of Interest

The author declares that she has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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