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STRUCTURAL ANALYSIS OF DIFFERENT HINGE POSITIONS ON THE MECHANICAL BEHAVIOR OF A WOODEN DOOR SYSTEM USING ANSYS

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ABSTRACT

This study investigates the effect of different hinge configurations on the mechanical performance of a wooden door system using finite element analysis. Two configurations were evaluated: one where the middle hinge was positioned closer to the upper hinge, and the other where it was centrally positioned. The results show that the maximum von Mises stress for the upper hinge configuration reached 75.614 MPa, while the centrally placed hinge configuration exhibited a slightly higher stress of 78.809 MPa. However, the central hinge placement provided more uniform stress and strain distribution across the door. Deformation values were also significant, with a maximum deformation of 0.0213 mm observed for the centrally positioned hinge, offering better load distribution compared to the upper hinge configuration. These findings suggest that the central hinge placement enhances the mechanical stability and lifespan of the door by reducing localized stress concentrations. The study highlights the importance of hinge positioning in optimizing the structural integrity of wooden door systems.

Keywords: Deformation and strain distribution, FEA, Hinge positioning, Von Mises stress, Wooden door.

1 INTRODUCTION

Wooden doors are commonly used as interior doors in residential buildings. These doors are typically referred to as swing doors and are attached to the frame using hinges, which allow the door to pivot open and closed [1]. The mechanical performance of door systems, particularly those constructed from wood, is heavily influenced by the positioning and configuration of hinges. Hinges act as critical load-bearing elements that transfer forces between the door and its frame. As a result, their placement directly impacts the structural integrity and durability of the entire system. Previous research in the field has largely focused on automotive and furniture doors, demonstrating that hinge configuration plays a crucial role in mitigating stress concentrations and minimizing deformation. Wooden doors, unlike their metal or composite counterparts, present unique mechanical challenges due to the anisotropic and heterogeneous properties of wood. These characteristics result in material behaviors that vary depending on the grain direction, significantly influencing how loads are distributed and absorbed. In the context of hinge positioning, these properties can exacerbate localized stress and strain concentrations, particularly in improperly positioned hinges. Such effects can lead to accelerated material fatigue and reduced durability of the door system. Addressing these challenges requires an in-depth evaluation of hinge configurations to optimize load sharing and minimize the adverse effects of wood's material properties. This study aims to investigate these aspects, providing insights into optimal hinge placement strategies for wooden doors.

Research into hinge configurations for automotive applications has shown that finite element analysis (FEA) can be effectively employed to optimize the placement and design of door hinges. Studies have indicated that optimizing the hinge layout significantly improves load distribution, thereby enhancing the door's mechanical strength. For instance, Liu et al. (2021) conducted a comprehensive study on vehicle door hinges using FEA to investigate vibration control and structural stability, underscoring the importance of hinge positioning in reducing stress concentrations under dynamic conditions [2]. Similar findings were reported by Erol and Özgül (2019), who explored the correlation between simulation and experimental results for door hinges subjected to regulatory tests. The study confirmed that optimal hinge configurations improve the load-bearing capacity of door systems [3]. Bayrak et al. (2025) conducted a finite element assessment of torsion springs in hinges, demonstrating the importance of accurate modeling and experimental validation in improving fatigue life and ensuring the durability of hinge components [4]. Bekah (2004) utilized finite element analysis to predict fatigue life in door hinge systems under uni-axial and multi-axial loading, identifying critical points of crack initiation and optimizing hinge design to enhance durability [5]. Meyer et al. (2023) developed novel test methods for the mechanical characterization of flexure hinges under large deformations, providing insights into stiffness properties crucial for designing compliant mechanisms [6]. Hwang et al. (2021) investigated the flexural anisotropy of rift-sawn softwood boards caused by end-grain orientation, revealing superior flexibility and deformation mechanisms beneficial for curved wooden applications [7].

In the context of furniture doors, a study by Zhongshan Four Seas Furniture Ltd. demonstrated the benefits of optimized hinge placement for wooden doors using ANSYS for FEA. This research revealed that doors with carefully positioned hinges exhibit reduced deformation and stress, even when subjected to high loads [8]. These findings highlight the importance of optimizing hinge configurations, not only for metal doors but also for wooden structures, where mechanical properties such as anisotropy and inhomogeneity can exacerbate stress concentrations if not properly accounted for.

In light of these findings, the present study employs ANSYS Structural Analysis to assess the impact of different hinge positions on the mechanical performance of a wooden door system. A complete pre-assembled press door set, including the frame, leaf, and trim, typically weighs around 35 kg. However, for the purposes of this study, only the weight of the door leaf itself has been considered, as the frame and trim do not contribute directly to the mechanical performance evaluated in this analysis. Two configurations are considered: one with the middle hinge placed centrally, and another with the middle hinge positioned closer to the upper hinge. The results of this analysis will contribute to a better understanding of the influence of hinge placement on stress and strain distributions, providing a basis for optimizing door design to enhance structural integrity and prolong service life.

2 MATERIAL AND METHOD

2.1 Wooden Door and Frame

The finite element analysis was conducted with several key assumptions to simplify the model and ensure computational efficiency. Firstly, the wooden material of the door was treated as isotropic, which does not fully capture the anisotropic nature of wood. While wood exhibits varying mechanical properties along its grain direction, isotropy was assumed to standardize the material behavior and simplify the simulation. This assumption may lead to an underestimation of strain concentrations along specific grain orientations. Secondly, rigid connections were applied at the contact points between the hinges and the door/frame. This simplification does not account for minor relative motions or deformations at the connections, which could slightly influence the stress distribution in real-world scenarios. Despite these limitations, these assumptions are commonly used in preliminary finite element models to balance accuracy with computational feasibility. The door and frame were modeled using oak wood, a material selected for its widely recognized structural properties in door systems. Oak wood is characterized by its high density, strength, and stiffness, making it a suitable material for load-bearing components in door assemblies [9]. The material properties for oak were sourced from ANSYS's material library, the mechanical properties were applied in the analysis, and demonstrated in table 1.

Table 1. Mechanical properties of oak wood and structural steel used in the finite element analysis of the door system [10].

Material	Density (kg/m^3)	Young's Modulus (GPa)	Poisson's Ratio
Oak Wood	935.7	22.7	0.3742
Structural Steel	7850	200	0.3

These values were chosen based on the general mechanical properties of oak wood, which has been well-documented for its durability and resistance to deformation under compression and bending loads. The hinges and all associated fastening elements, including bolts, were modeled using structural steel. Structural steel was selected for its superior tensile strength and durability, particularly in applications involving load transfer through mechanical connections. The material properties for structural steel, also sourced from ANSYS's material library (Table 1.).

The wooden door and frame geometries were designed with precise dimensions to reflect real-world door systems. The door's dimensions were 2000 mm in height, 790 mm in width, and 42 mm in thickness. The frame was modeled with an external height of 2140 mm, a width of 942.5 mm, and a thickness of 260 mm (detailed in Figure 1.(a)). The selected dimensions align closely with the TS 825 standard, which defines typical door measurements for interior applications in Türkiye [11]. Both the frame and door were designed as solid models, and the hinge positions were adjusted according to two configurations. In this study, two hinge configurations were examined to assess their impact on the mechanical performance of a wooden door system. The first configuration placed the middle hinge closer to the upper hinge (Figure 1.(c)), concentrating the load toward the top of the door. The second configuration positioned the middle hinge centrally, aiming to distribute the load more evenly across the entire door (Figure 1.(b)). These two setups were analyzed using finite element analysis to compare their effects on stress, strain, and deformation, providing insights into the benefits and limitations of each configuration for enhancing the structural integrity and durability of the door system.

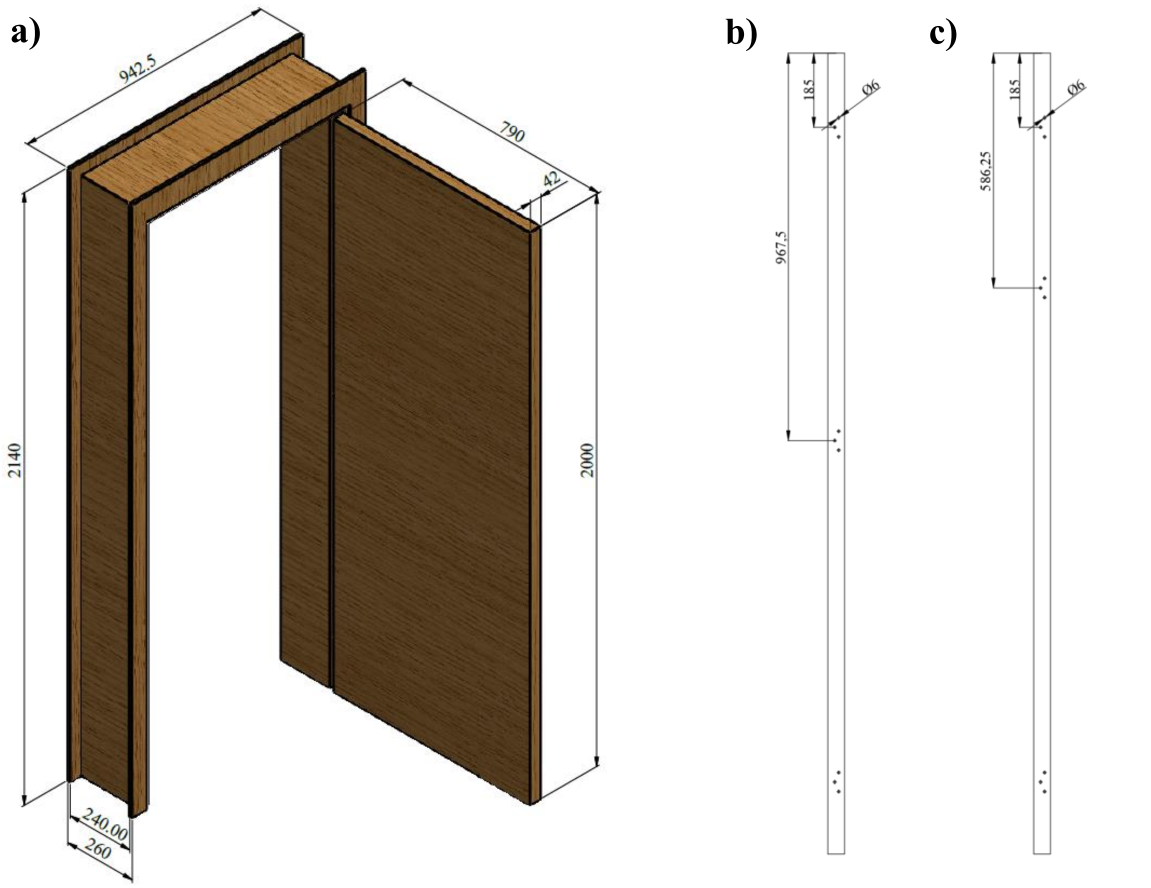

Figure 1. Dimensional schematic of the wooden door system, showing the full assembly and hinge placements. (a) Overall dimensions of the door and frame assembly, (b) hinge placement with the middle hinge centrally positioned, and (c) hinge placement with the middle hinge closer to the upper hinge.

2.2 Finite Element Modeling

Finite element analysis (FEA) was performed using ANSYS Workbench 2022. A 3D solid model of the door, frame, hinges, and bolts was created. The system was meshed using tetrahedral elements, which were generated by ANSYS Meshing tool. The finite element model for the door system was created with 2,761,628 nodes and 1,895,191 elements, utilizing a tetrahedral mesh to accurately capture the complex geometry around the hinges and bolts. The average skewness of the mesh was 0.25033, which falls into the very good range (0.25–0.50), indicating minimal distortion and reliable element quality. The average orthogonal quality was 0.76953, placing it in the very good range (0.70–0.95), further ensuring the mesh's suitability for detailed stress and strain analysis. This high-quality mesh allowed for accurate and reliable simulation results in the finite element analysis [12], [13], [14], [15].

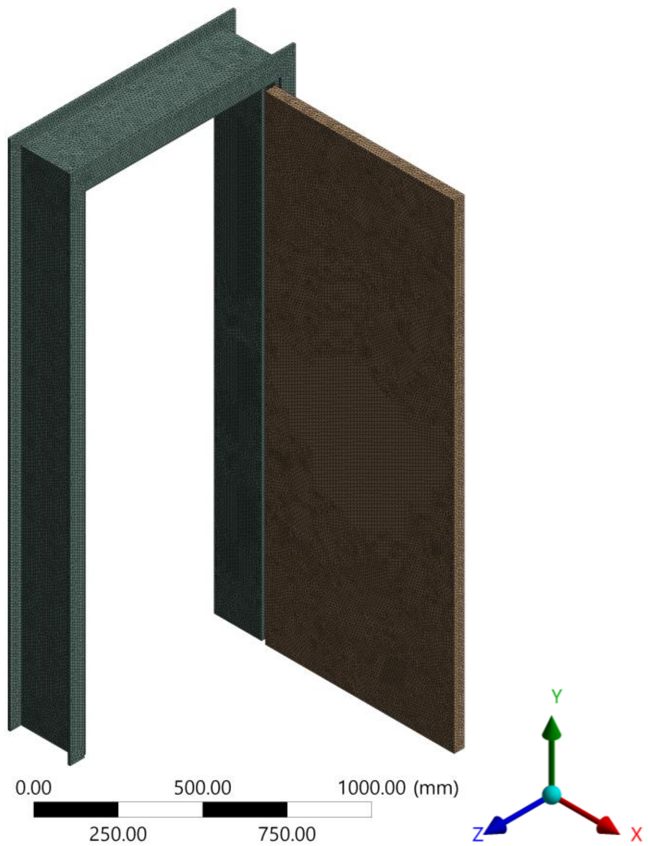

Figure 2. Mesh structure of the door system. The average skewness (0.25033) and orthogonal quality (0.76953) indicate a high-quality mesh suitable for accurate stress and strain analysis.

The analysis was conducted under standard earth gravity conditions (9.81 m/s²), with no additional external forces applied to the system. To simulate the real-world attachment of the door frame to the surrounding structure, the regions where the door frame contacts the wall were modeled using fixed support boundary conditions. This ensured that the frame remained stationary during the analysis, accurately reflecting its role in bearing the load transferred through the door and hinges. The contact interactions between the door, hinges, and bolts were modeled as bonded contacts, simulating a rigid connection where no relative movement or separation occurs between these components. This approach provides a realistic representation of the mechanical connections within the door system, ensuring accurate stress, strain, and deformation results in the finite element analysis. The analysis was conducted using a static structural analysis in ANSYS. The solver was set to account for large deflections, and non-linear material behavior was included to capture any plastic deformation in the hinges and bolts. The results focused on deformation, strain, and von Mises stress across the system for both hinge configurations. Key results were extracted from the simulation, including total deformation (mm), strain (mm/mm), and von Mises stress (MPa). These results were used to compare the mechanical behavior of the two hinge configurations. Stress and strain contours were plotted to visually represent areas of high deformation and potential failure points.

For isotropic materials, the relationship between stress and strain is governed by Hooke's Law. In the case of linear elasticity, this is represented by the following equation:

$$\sigma = E.\varepsilon \tag{1}$$

where:

σ is the stress (Pa or MPa)

E is the Young's Modulus (Pa or GPa)

ε is the strain

This equation applies to the linear elastic range of both oak wood and structural steel used in the analysis. In structural analysis, the von Mises stress is used to predict yielding of ductile materials. It's calculated using the following equation:

$$\sigma_v = \sqrt{\frac{1}{2}[(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2]} \tag{2}$$

where:

σ_v is the von Mises Stress (Pa or MPa)

σ_1, σ_2, σ_3 are the principal stresses in the system

This criterion was used to assess whether the structural steel components (hinges and bolts) remain within the elastic limit during the loading conditions.

The total deformation δ in a body under load can be expressed as a function of applied force F, length L, cross-sectional area A, and Young's Modulus E:

$$\delta = \frac{F.L}{A.E} \tag{3}$$

This equation helps in understanding the relationship between the applied forces and the resulting deformation in the door and frame, considering the material properties of oak wood.

Strain (ε is defined as the ratio of change in length ΔL to the original length L_0

$$\varepsilon = \frac{\Delta L}{L_0} \tag{4}$$

Strain is a dimensionless quantity that was calculated for various components in the system to assess how the door and hinges deformed under load.

3 RESULTS AND DISCUSSION

The FEA results presented in Figure 3. illustrate the deformation contours for two different hinge configurations of a wooden door system. The figure is organized into two rows and four columns, where each column represents a different set of components analyzed within the system. The first row corresponds to the case where the middle hinge is positioned closer to the upper hinge, while the second row represents the configuration where the middle hinge is centrally located.

The first contour plot on the left shows the deformation distribution for the entire door system, including the door, frame, hinges, and bolts. The maximum deformation in this configuration is observed at approximately 0.0237 mm, which occurs at the free end of the door. The deformations are relatively more concentrated at the top corner of the door, reflecting the hinge position's influence on the door’s structural response. The second plot focuses on the door's deformation only, excluding the frame and other components. The highest deformation reaches 0.0237 mm, again concentrated at the top corner. This distribution suggests that the door’s upper part experiences the most significant deformation, potentially due to the closer proximity of the middle hinge to the upper hinge, reducing the support near the center of the door. The third contour plot shows the deformation of the door frame alone. The frame experiences a maximum deformation of 0.00076 mm, indicating minimal displacement, which suggests that the frame structure remains rigid and unaffected by the hinge position. The final plot in this row presents the deformation of the hinges and bolts. The maximum deformation in this configuration is 0.00929 mm, indicating some deformation within the connecting elements but not significant enough to affect the overall assembly’s integrity.

In the second row, where the middle hinge is centrally located, the total assembly deformation is again analyzed. The maximum deformation remains at 0.0213 mm. Compared to the first configuration, the overall deformation is slightly reduced, suggesting that central hinge positioning may improve the load distribution across the door. The deformation of the door alone shows a similar pattern to the first configuration, with a maximum of 0.0213 mm. However, the stress distribution appears more uniform compared to the closer hinge configuration, indicating that the central hinge may provide better load balance. The door frame deformation remains minimal, with a maximum of 0.00089 mm. This value is slightly higher than in the first configuration, but still negligible, reinforcing the structural rigidity of the frame. The deformation in the hinges and bolts is again highlighted, with a maximum deformation of

0.00858 mm. This is slightly lower than in the first configuration, suggesting that the central positioning of the hinge reduces the stress on the connecting elements.

A comparison between the two hinge configurations reveals that the middle hinge's position significantly affects the deformation patterns within the door system. When the middle hinge is positioned closer to the upper hinge, the deformation is more concentrated at the top of the door, leading to higher stress concentrations in that area. In contrast, when the middle hinge is centrally positioned, the deformation is more evenly distributed, reducing the overall stress on the door and its components. This suggests that a central hinge position may provide better mechanical performance by improving load distribution and reducing localized stress concentrations.

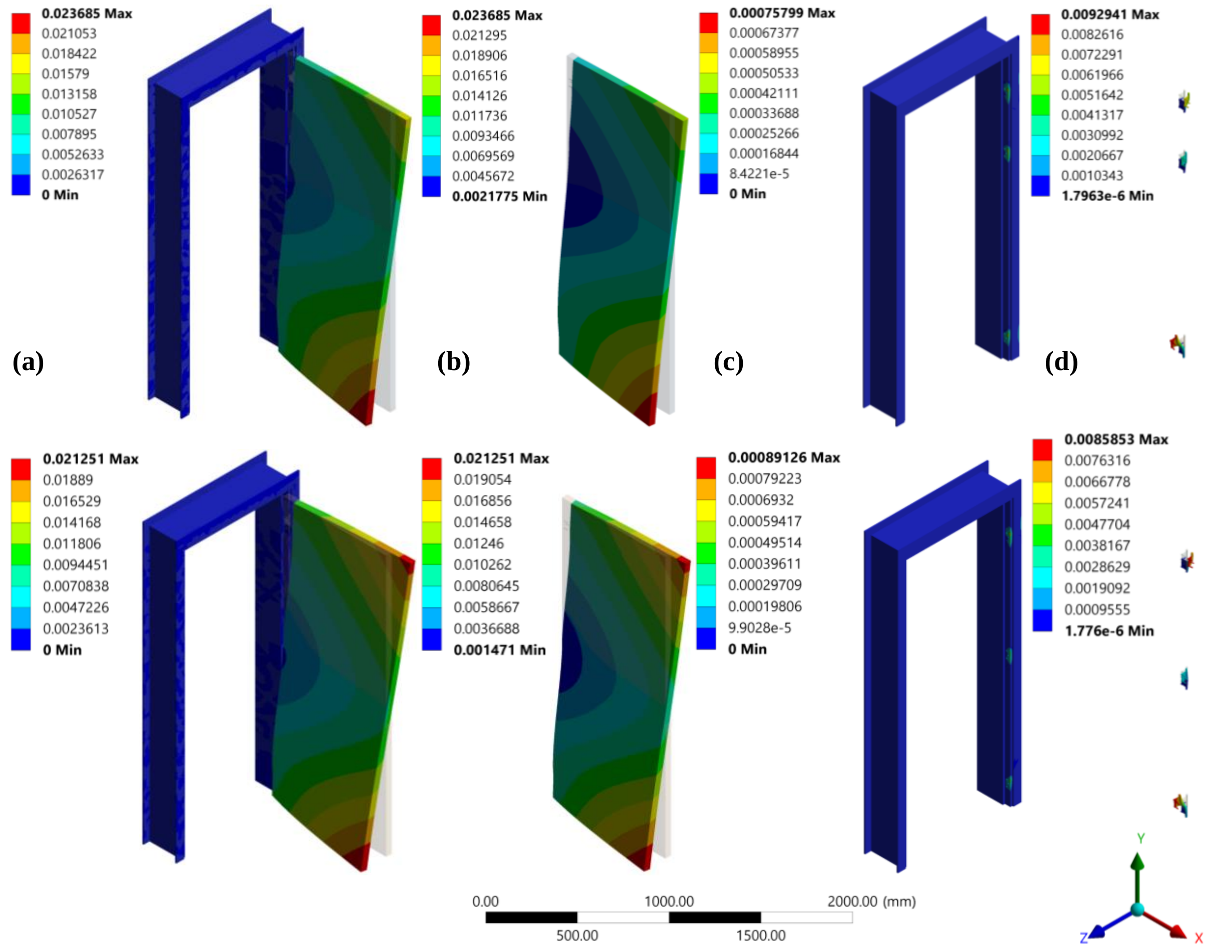

Figure 3. Deformation contours (mm) for two hinge configurations of a wooden door system. The first row illustrates the configuration with the middle hinge closer to the upper hinge, while the second row shows the middle hinge centrally located. The columns display (a) the total assembly, (b) the door, (c) the frame, and (d) the hinges and bolts. The centrally placed hinge results in more uniform deformation, while the upper hinge configuration shows higher localized deformation near the upper part of the door.

The results shown in Figure 4 depict the strain distributions (in mm/mm) for the two different hinge configurations of a wooden door system. The first row represents the configuration where the middle hinge is positioned closer to the upper hinge, while the second row corresponds to the configuration with the middle hinge centrally located. Each column highlights the strain contours of different components of the door system, providing insights into how hinge positioning influences the strain distribution across the assembly.

The strain distribution for the entire door system, including the door, frame, hinges, and bolts, is shown in the first contour plot. The maximum strain observed is approximately 0.00046277 mm/mm, with strain concentration localized at the door edges, particularly near the upper hinge area. This indicates that positioning the middle hinge closer to the upper hinge leads to higher localized strain in the upper part of the door. The second plot isolates the strain distribution within the door itself. The maximum strain is 0.0002309 mm/mm, and the strain is primarily concentrated near the upper corner of the door, corresponding to the location of the upper hinge. This suggests that the closer proximity of the middle hinge to the upper hinge leads to less even strain distribution, with a greater focus near the top. The third contour plot shows the strain distribution in the door frame. The maximum strain here is significantly lower, at 0.00010039 mm/mm, indicating that the frame experiences minimal strain, reinforcing its structural rigidity. However, the strain is still somewhat concentrated in areas close to the hinges. In the final plot, the strain within the hinges and bolts is displayed, with a maximum strain of 0.00046277 mm/mm. This suggests moderate strain accumulation in the connecting elements, though it remains within a low range. The higher strain around the upper hinge reflects the positioning's impact on the overall assembly. The total strain distribution for the system when the middle hinge is centrally positioned reveals a maximum strain of 0.00048654 mm/mm, slightly higher than in the first configuration. The strain appears more uniformly distributed across the door, indicating a more balanced load distribution due to the central positioning of the hinge. The door's strain in this configuration shows a maximum value of 0.00024153 mm/mm, and the strain is more evenly distributed compared to the first configuration. This suggests that the central hinge provides better support, leading to a more uniform strain profile across the door's surface. The frame strain remains minimal, with a maximum strain of 0.00010435 mm/mm. This is slightly higher than the first configuration but still indicates that the frame is largely unaffected by hinge positioning, retaining its rigidity. The strain in the hinges and bolts in this configuration has a maximum value of 0.00048654 mm/mm, indicating a more distributed strain compared to the first configuration. This suggests that placing the middle hinge centrally reduces localized strain, improving the load distribution across the connecting elements.

The strain analysis reveals that the middle hinge's position has a significant effect on the strain distribution within the door system. When the middle hinge is placed closer to the upper hinge, higher strain concentrations are observed in the upper part of the door, potentially leading to increased wear in that area. In contrast, when the middle hinge is centrally positioned, the strain is more evenly distributed, reducing localized stress and improving the overall mechanical performance of the system. These findings suggest that central hinge positioning may enhance the long-term durability of wooden door systems by minimizing strain concentrations.

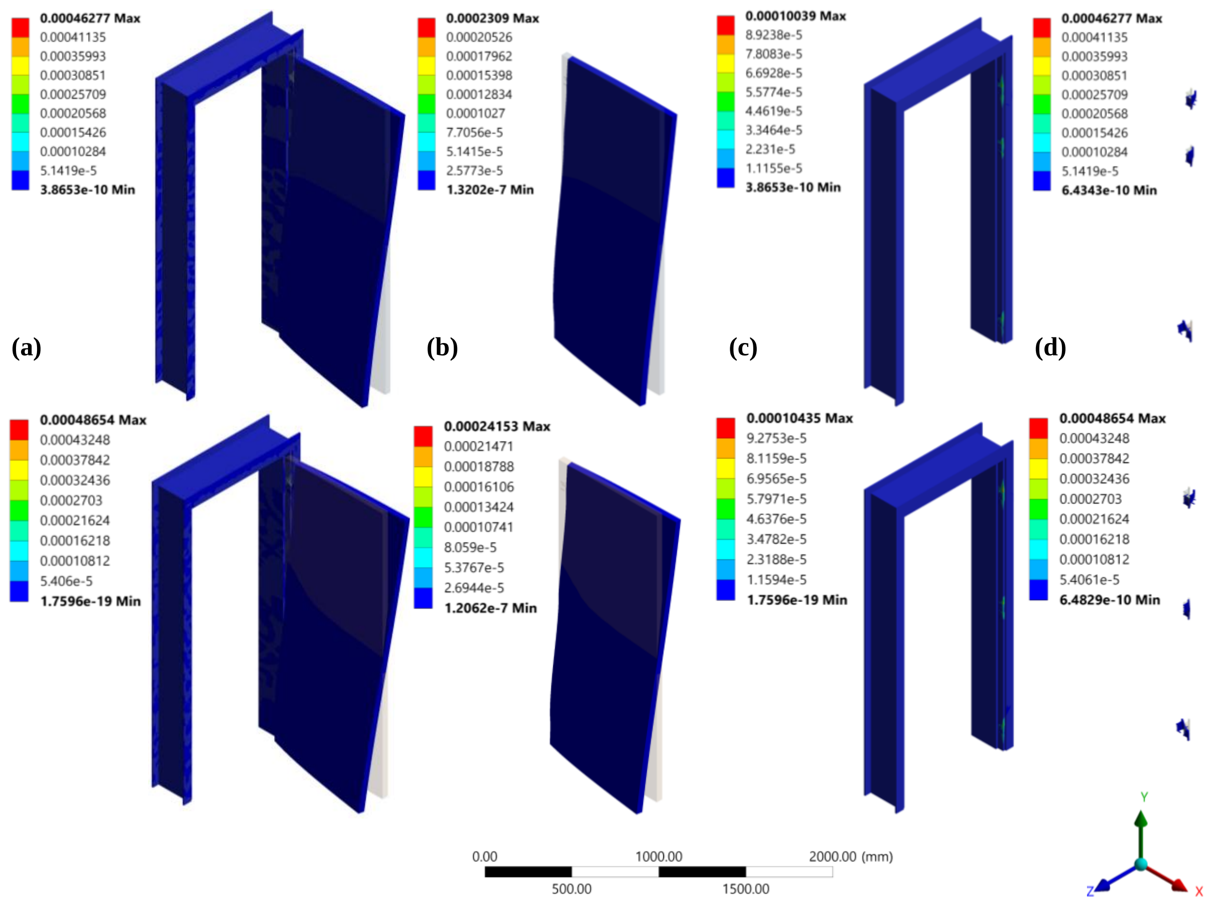

Figure 4. Strain contours (mm/mm) for two hinge configurations of a wooden door system. The first row shows the middle hinge positioned closer to the upper hinge, and the second row shows the middle hinge centrally located. The columns represent (a) the total assembly, (b) the door, (c) the frame, and (d) the hinges and bolts. Central hinge placement significantly reduces strain concentrations compared to the upper hinge configuration.

The stress contours (in MPa) shown in Figure 5 offer an in-depth look into the stress distribution across different parts of the wooden door system for two hinge configurations. The figure consists of two rows and four columns, with the first row representing the configuration where the middle hinge is closer to the upper hinge, and the second row showing the middle hinge in a central position. Each column corresponds to different components of the system, highlighting their stress responses under loading.

The first contour plot in the top-left corner shows the stress distribution for the entire door system, including the door, frame, hinges, and bolts. The maximum von Mises stress is 75.614 MPa, and it is concentrated near the upper section of the door, particularly around the hinges and frame connections. This concentration indicates that the closer positioning of the middle hinge to the upper hinge results in higher stress in these areas. The second plot focuses solely on the door's stress distribution. The maximum stress value here is 2.264 MPa, and it is concentrated near the upper corner of the door. The stress is more localized, likely because the middle hinge being closer to the upper hinge limits load transfer across the entire door, causing higher stress in the upper region. The third plot shows the stress distribution within the door frame, with a maximum stress of 75.614 MPa. The frame experiences significant stress near the hinge attachments, especially at the top. This high stress concentration indicates that the frame bears most of the load when the middle hinge is positioned near the top. The final plot in the first row highlights the stress in the hinges and bolts. The maximum stress is 4.8867 MPa, and it is primarily located around the connections between the hinges and the frame. This stress concentration near the upper hinge suggests that this configuration places considerable stress on the upper joint components.

In the second row, where the middle hinge is centrally located, the overall stress distribution for the door system shows a maximum stress of 78.809 MPa. This is slightly higher than the first configuration, but the stress appears more evenly distributed across the door, frame, and hinges, suggesting better load sharing across the system. The door alone experiences a maximum stress of 2.0502 MPa in this configuration, slightly lower than in the previous setup. The stress distribution is also more uniform, indicating that the central hinge allows for better stress management along the length of the door. The frame shows a maximum stress of 78.809 MPa, similar to the first configuration. However, the stress concentration is more distributed along the frame, particularly around the middle hinge area, which reduces the peak stress near the upper part of the frame. The final plot focuses on the stress within the hinges and bolts, with a maximum stress of 5.0971 MPa. This stress is concentrated near the middle and upper hinges, indicating that the central hinge configuration distributes the load more evenly across all the connecting elements, resulting in a more balanced stress profile.

The stress analysis highlights significant differences between the two hinge configurations. When the middle hinge is positioned closer to the upper hinge, stress concentrations occur in the upper region of both the door and frame, with higher stress in the bolts and hinges as well. In contrast, when the middle hinge is centrally located, the stress is more evenly distributed across the door and frame, and the overall system experiences better load sharing. This suggests that the central hinge configuration is more effective in reducing localized stress concentrations, which may improve the durability and performance of the door system.

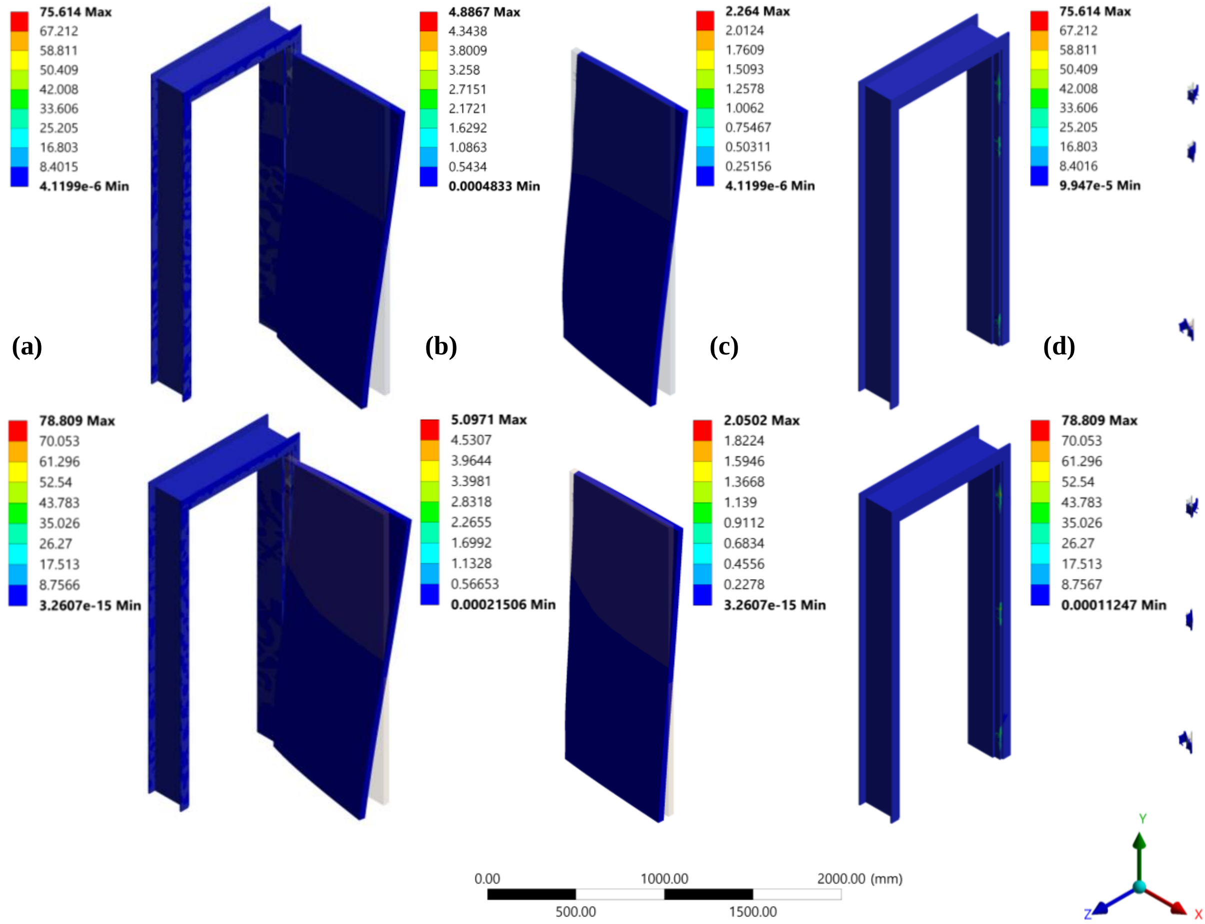

Figure 5. Von Mises stress contours (MPa) for two hinge configurations of a wooden door system. The first row shows the middle hinge positioned closer to the upper hinge, and the second row shows the hinge centrally located. The columns represent (a) the total assembly, (b) the door, (c) the frame, and (d) the hinges and bolts. The upper hinge configuration exhibits higher stress concentrations at the top of the door, whereas the central hinge configuration provides a more balanced stress distribution.

The results of this study, which analyzed different hinge configurations in a wooden door system, show distinct differences in the mechanical behavior of the system. These findings align with similar research on door hinges, particularly regarding the effects of deformation, stress, and strain distribution.

The configuration where the middle hinge was placed closer to the upper hinge showed more localized deformation near the top section of the door. This result is consistent with the findings of Zhou et al. (2012), who observed that improper hinge placement can lead to increased deformation at hinge attachment points, especially when hinges are placed too close to one another. Their study demonstrated that multiple hinge placements could help distribute loads more effectively and reduce overall deformation [8], [16]. A similar outcome was observed in Seker et al. (2021), who studied cabinet doors and found that deformation increased significantly when hinge distribution was not optimized, particularly in two-hinge systems [16]. The centrally placed hinge configuration in the current study resulted in more uniform deformation, confirming that well-spaced hinge placement improves load distribution and structural integrity.

Strain analysis further supports the benefits of central hinge placement, as this configuration exhibited lower strain values compared to the upper hinge placement. Studies by Seker et al. and Zhou et al. (2012) also highlighted that optimal hinge positioning reduces strain concentrations, particularly in high-load areas. Seker et al. noted that uneven hinge distribution in cabinet doors leads to higher strain and greater material fatigue over time, while Zhou et al. demonstrated similar strain behavior in their research on furniture doors [8], [16]. The current study's findings echo these results, showing that central hinge placement promotes a more even distribution of strain across the door's length, reducing the risk of localized strain-induced damage. The results presented in this study are based on static loading conditions, which represent typical operational forces applied to wooden doors. However, in real-world applications, doors may experience dynamic or variable loading, such as impacts, cyclic forces from repeated use, or wind loads. Dynamic loading could introduce additional stress and strain variations, potentially amplifying localized stress concentrations, especially near hinge attachment points. Furthermore, cyclic loading might accelerate material fatigue, particularly in wooden doors with anisotropic properties. Future studies could address these aspects by incorporating time-dependent (dynamic) analyses or fatigue simulations to provide a more comprehensive understanding of the door system's performance under variable loading conditions.

The stress distribution analysis further highlighted that placing the middle hinge closer to the upper hinge resulted in higher stress concentrations at the top of the door and the frame, which could increase the risk of localized failure over time. Erol and Özgül (2019) reported similar behavior in automotive doors, where closely spaced hinges led to stress peaks under operational loads [3]. The central hinge configuration, on the other hand, showed a more balanced stress distribution across the door and frame, which could improve the long-term durability of the door system by reducing the likelihood of material failure. This finding is in line with the work of Isobe and Sato (2023), who found that reducing stress concentrations, especially during seismic events, can significantly improve door performance and longevity [17].

4 CONCLUSION

The finite element analysis of the wooden door system with varying hinge configurations has revealed significant insights into how hinge positioning affects the door's mechanical performance. The key findings of the study are summarized below:

- The configuration with the middle hinge closer to the upper hinge exhibited a maximum von Mises stress of 75.614 MPa in the frame, while the centrally placed hinge configuration showed a slightly higher stress of 78.809 MPa. Despite this, the central configuration provided more balanced load distribution.
- The centrally positioned hinge configuration resulted in a maximum deformation of 0.0213 mm, with a more uniform deformation profile compared to the upper hinge configuration, where deformation was localized near the upper part of the door.
- The central hinge placement significantly reduced localized stress and strain concentrations, suggesting improved structural integrity and prolonged service life for the door system.
- From a practical perspective, centrally placed hinges are recommended for high-use environments, such as residential and commercial settings, where durability and load balance are critical.
- For larger or heavier doors, designers may consider using additional hinges to further enhance load distribution.

This study serves as a practical reference for optimizing hinge placement in wooden door systems, offering insights into how minor adjustments in design can lead to significant improvements in mechanical performance. Future research could explore additional variables such as material properties, hinge stiffness, and dynamic loading conditions to refine the findings and apply them to a wider range of door designs and materials.

Conflict of Interest Statement

There is no conflict of interest between the authors.

Statement of Research and Publication Ethics

The study is complied with research and publication ethics.

Artificial Intelligence (AI) Contribution Statement

Artificial intelligence (AI) tools, including language models, were used solely for language editing, grammar corrections, and improving the fluency of the manuscript. No AI tools were involved in the generation of original content, data analysis, or interpretation of results.

Contributions of the Authors

Yasin Furkan GÖRGÜLÜ: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing.

Rahim MERDAN: Conceptualization, Methodology, Writing – original draft.

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