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Finite Elements Method Investigation of Plates with Varied Support and Opening for Design Optimization

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A B S T R A C T

Plates have an important function in supporting the structural load above them. One important aspect of plate design is the design of the openings or holes. These openings can be needed for various purposes, such as pipe installation, ventilation, and ducts. If the plate openings are not designed carefully, it will cause serious problems such as excessive deflection. This increases the risk of structural accidents and ultimately threatens the safety of building users. This study aims to determine the effect of plates with different types of supports and opening models with 3D modeling. Quantitative descriptive research using the finite element method was used. There are 16 models with different support types (simply and fixed) and opening models (rectangular, square and circular). From the modeling, the deformation and stress values that occur will be obtained. Comparative analysis is carried out to obtain the best support and opening types. The research results show that the increase in stress concentration tends to be higher in rectangular openings, while in square and circular openings, it is smaller than in plates without openings. Circular shapes tend to have high deformation values. Meanwhile, the square shape has the smallest value compared to all models. Simply support has greater stress in rectangular and circular openings. 4-sided fixed support is the best choice because it has the smallest stress and deformation values. Through these results, it is possible to optimize the design of appropriate types of supports and openings to reduce excess stress and improve overall structural performance.

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1. Introduction

In the construction world, structural elements are the main priority that must be considered. A structure must withstand the load during the service life of the building [1]. Building components have structural elements: columns, beams, and floor plates [2]. Plates have an important function in supporting the structural load above them. One important aspect of plate design is the design of the openings or holes. These openings can be needed for various purposes, such as pipe installation, ventilation, and ducts for essential needs such as electricity, telephone, water supply, internet networks, exhaust, and cooling machines [3]. Generally, there are three opening shapes: square, circle, and rectangle [4], [5]. Opening plates can reduce the stiffness and mass of the structure, thereby reducing its weight and earthquake loads [6]. Events like this require special handling because they impact the structure's performance [7]. If the plate openings are not designed carefully, it will cause serious problems such as excessive deflection. This increases the risk of structural accidents and ultimately threatens the safety of building users.

Analysis of the performance of plate structures is an interesting and important research focus. The classical plate theory analysis approach is difficult to achieve in describing plate behavior. Therefore, modeling using numerical methods that are widely used is the finite element method (FEM) appears as an alternative to simplify plate opening calculations. Modeling plays an important role in thoroughly understanding how openings in a slab can affect structural performance and its ability to provide deep and predictive insight into the structural response to design variations [5]. Using finite element modeling techniques, various scenarios and load models can be simulated to determine the most appropriate design or identify potential problems and analyze their impact on the strength of the structure.

Plate modeling using FEM can reveal the stress behavior that occurs in structures with more complicated combinations. Several studies analyzed the effect of openings on floor plates, which focused more on the influence of deformation values on the plate structure, without analyzing the stresses that occurred in the structure [7][3][4]. Singh et al. [4] modeled using the finite element method to determine the deformation and stress that occurs in plate structures with variations in the shape of openings and without openings. The modeling shows that the deformation and stress increase in the surrounding area is not the greatest in plates with simple supports. The greatest increase in stress and deformation occurs in rectangular openings, while circular openings produce the smallest stress and deformation values [4]. On the other hand, researchers also conducted studies regarding the influence of the type of support. Analyzing

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flexible plates shows that simple supports have higher stresses and deformations than other supports [3]. Variations in the shape of the opening and the type of support will have an important impact on the strength, stiffness, global stability, and safety of the structure [5] [8] [9]. Previous research has investigated the combined effect of variations in support type and opening shape on structural performance using finite element analysis in 2-dimensional space. The findings provide insight into structural behavior from a two-way perspective.

However, research focusing on three-dimensional variations in analyzing support types and damage forms is still limited. The 3D analysis will provide an understanding of the overall structural response. This study aims to determine the effect of plates with different types of supports and opening models with 3D modeling. The research results are hoped to guide choosing the appropriate type of support and openings to reduce excessive stress and improve overall structural performance.

2. Research Method

This quantitative descriptive study uses a finite element approach modeling plates with variations in opening shapes, support types, and models. Analysis was carried out on deformation and stress points around the openings compared to plates without openings. Data collection is done in real-time based on stress analysis in each part of the model, producing stress contours, main stress, and maximum and minimum stress. A comparative analysis was carried out on sixteen plate variables with different characteristics to gain a better understanding.

2.1 Model of Plate

A total of 16 plate models were used with the following specifications.

Table 1. Specification of Materials.

Description	Value
Compressive strength (f'c)	28MPa
Modulus of Elasticity (E)	24870.06 MPa
Poisson ratio	0.15
Stress yield	240 MPa
stirrups	ϕ 10-150
Shape	Square plate
Dimension	3000 x 3000 mm
Thickness	120mm

Source: Author Research Method (2023).

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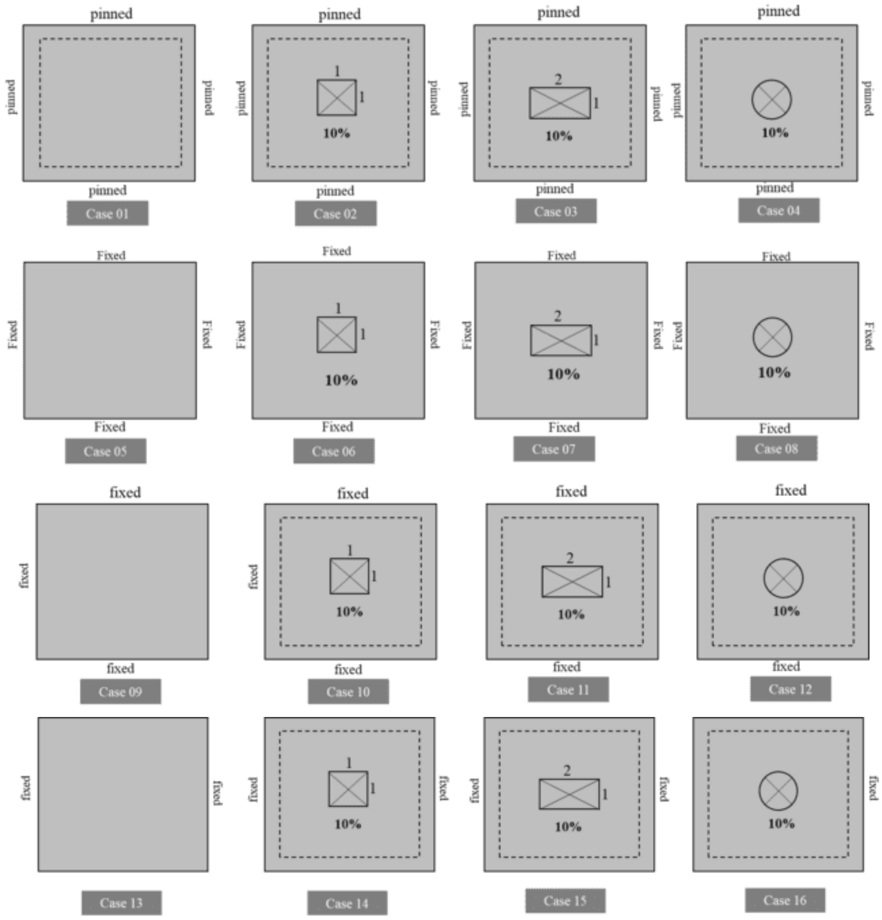
A total of 16 plate models were used, which were sourced from [4]. The model is divided into 4, each with 4 cases, namely without, square, rectangular, and circular openings. The proportion of openings is 10%. Model 1 uses simple support, Model 2 uses fixed support on four sides, Model 3 uses fixed support on three sides, and Model 4 uses fixed support on two opposite sides.



Sources: Prem Singh and Leo S. Tedianto (2022) [4]

Figure 1. Modelling plate on FEM

2.2 FEM Modeling

The basic concept of the finite element method is used to solve a problem by dividing the analysis object into small, limited components (meshing). These small components are then analyzed separately. This method was tested to calculate plates with various geometric shapes, including irregular, in this case, having openings. The analysis results on these small components are then combined again to solve the problem being considered.

The FEM modeling process begins by including properties such as specific gravity, modulus of elasticity, and Poisson's ratio. After that, assembly is carried out to place the model

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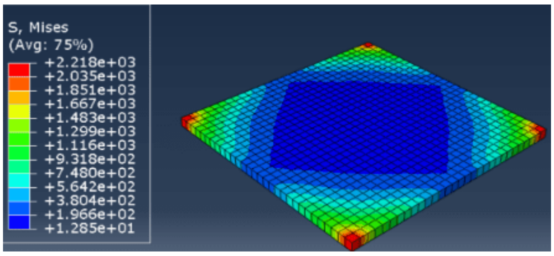
in the desired direction. The uniform load is entered referring to Prem Singh et al. [4], and the typical weight is based on H. Abd El-Mottaleb et al. [10], which includes self-weight and is applied to the plate. After loading, meshing is carried out by dividing the domain into several elements. Meshing is done by selecting the appropriate element type and size for the material being analyzed [11].

3. Results and Discussions

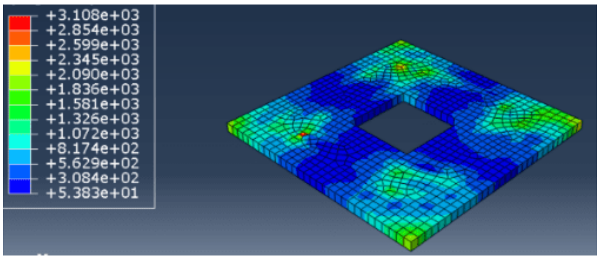
3.1 Models 1 and 2

Model 1 represents simple supports, while Model 2 represents supports fixed on all four sides. Analysis was carried out on the stresses and deformation that occurred in the two models.

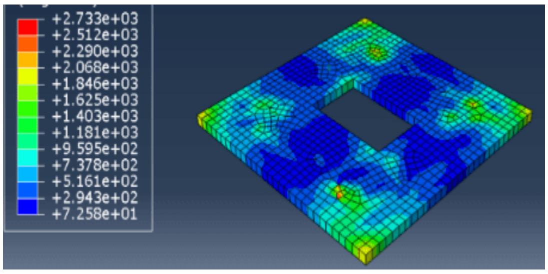
3.1.1 Stress



(a)



(b)



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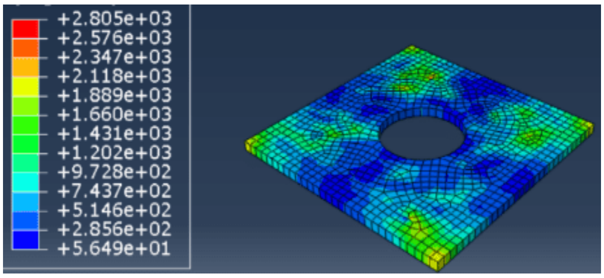

(d)

Sources: Author's Analysis Results.

Figure 2. Stress in Plate with Simply Supported; (a) Without Openings; (b) Square Openings; (c) Rectangular Openings; (d) Circular Openings.

The stress distribution shows relatively even characteristics over the entire surface in plates without openings with simple support. This is because there is no major disturbance in load distribution or structure. The stress is centered on each corner of the plate, and the middle section tends to experience smaller stress. The support joint allows the plate to rotate freely around a specific axis. When a load is applied, the endpoints become the focus of stress redistribution because they are the points where free rotation occurs. The plate's center tends to

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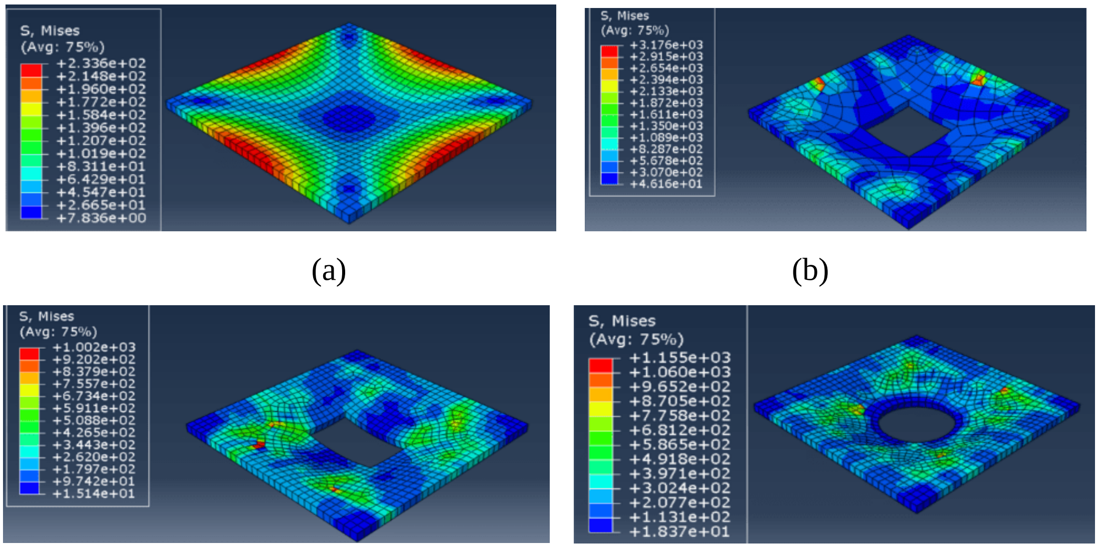
experience smaller stresses because it is far from stress sources that concentrate at the corners of the plate.

The stress distribution of plates with openings tends to have a similar pattern to plates without openings but with increased stress around the area of the openings. Changes in the stress distribution along the plate cause this. Parts adjacent to the edges or rims of openings tend to experience higher stress concentrations due to the local effects of changes in geometry. The stress distribution tends to move towards the opening, resulting in higher stress than the surrounding area.



(a) (b)

(c) (d)

Sources: Author's Analysis Results.

Figure 3. Stress in Plate with Fixed Support at Four Sides; (a) Without Openings; (b) Square Openings; (c) Rectangular Openings; (d) Circular Openings.

In contrast to simply support, a plate without openings with fixed support has a stress distribution that tends to increase exponentially away from the center point and reaches a maximum value around the edge of the plate (not just at the angle of the plate). Fixed pedestals cause changes in stress distribution along the plate due to resistance to the movement of the plate in its pedestal area. When a load is applied to the plates, the fulcrum becomes the area where the movement or deformation of the plates is inhibited.

Meanwhile, in a square opening, high stress does not occur around the opening; it only occurs at the edge of the plate. In contrast to rectangular and circular openings, the stress increases as one approaches the opening, and the minimum stress occurs at the edge of the plate.

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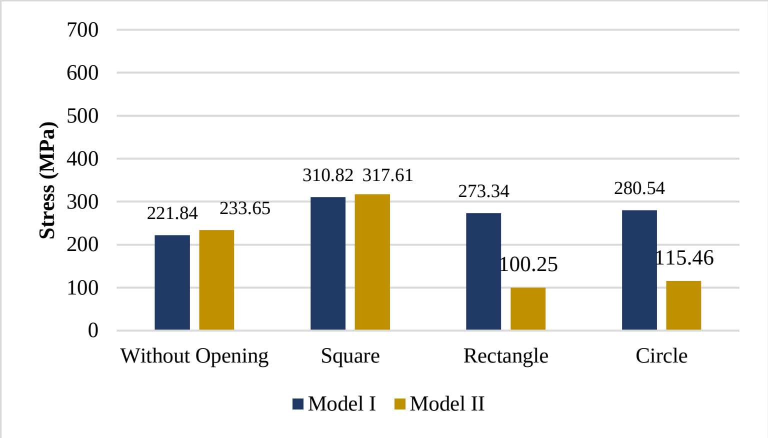

Sources: Author's Analysis Results.

Figure 4. Stress at Model I and II

Figure 4 shows the Von misses stress in models I and II. Both plates with simple supports and fixed supports show that plates without openings have smaller stresses compared to plates with overall openings. Plates with openings for rectangle openings have a smaller stress value compared to other plates. In model I, the stress value is 23.21% higher than the plate without openings, while in model II, the stress value is 13% compared to plates without openings [9][10]. Model II (fixed support) has better performance when compared to Model I (simply support) on plates with openings. The smaller stresses at rectangular and circular openings indicate this. It can be seen that simply and fixed support have significant differences. The characteristics of the support reactions and structural behavior of both can explain these differences. In models with fixed support, the plate is completely restrained at the edges, creating conditions where deformation and displacement at the edges are limited. This causes an even distribution of stress along the edge. On the other hand, in the simply supported model, the plate is allowed to move freely at the edge. Therefore, the deformation and displacement at the edges are not completely restricted. The stress distribution becomes varied, with lower peak stress values in the center of the plate. Excess deformation and sliding along edges can reduce stress values in some areas, providing a more flexible response to applied loads.

Apart from support, opening geometry is also important in designing openings. The shape of the opening can change the stress flow path and cause uneven stress redistribution. Many studies reveal that the presence of openings in a plate will reduce the strength of the plate itself [10]. The opening will become a stress concentrator, causing an increase in stress around the edges of the opening and a distribution of load along those edges. The presence of openings creates interactions between the structure and the openings, influencing stress flow and deformation around the area.

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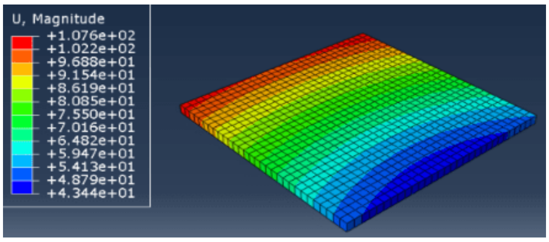
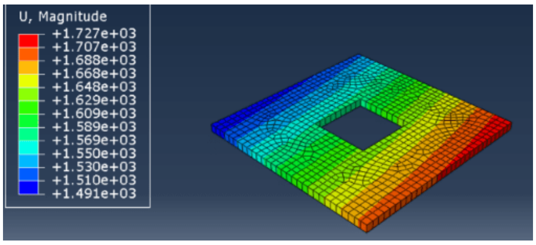
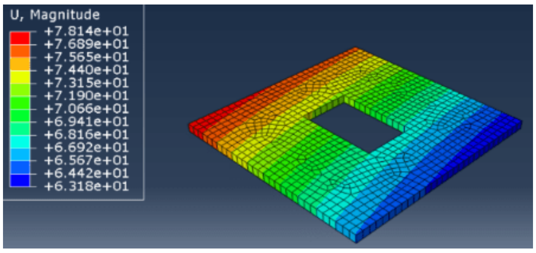
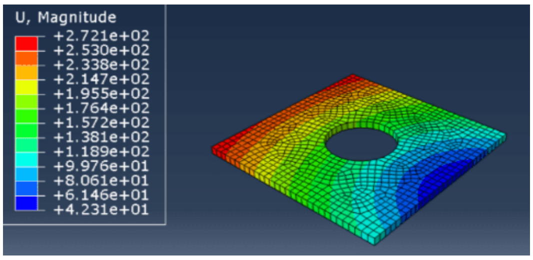
3.1.2 Deformation





(a) (b)



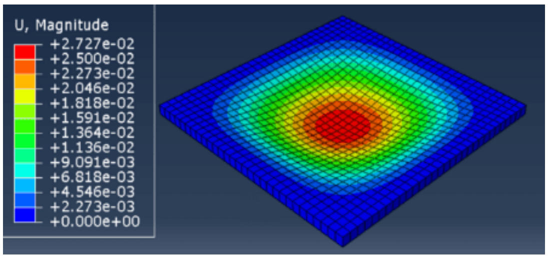


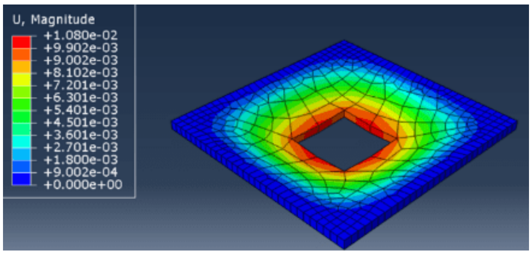
(c) (d)

Sources: Author's Analysis Results.

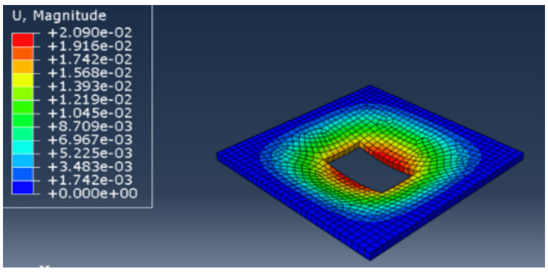
Figure 5. Deformation in Plate with Simply Supported; (a) Without Openings; (b) Square Openings; (c) Rectangular Openings; (d) Circular Openings.

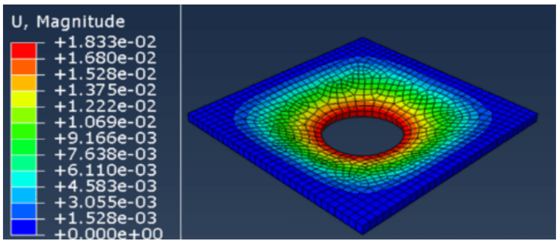
The deformation of plates with simply support shows characteristics that align with the support's nature. Deformation is evenly graded, with maximum deformation located at one edge of the plate.





(a) (b)





(c) (d)

Sources: Author's Analysis Results.

Figure 6. Deformation in Plate with Fixed Support at Four Sides; (a) Without Openings; (b) Square Openings; (c) Rectangular Openings; (d) Circular Openings.

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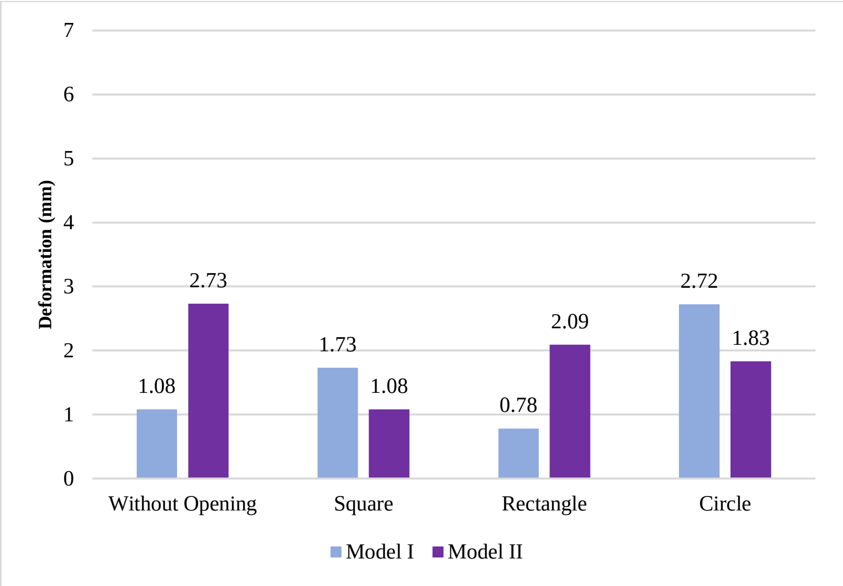
The deformation of plates without openings shows relatively uniform shape changes over the entire surface. Maximum deformation generally occurs in the middle of the plate following the uniform application of the load. The deformation tends to decrease linearly away from the center, creating flexural forms that can be described as patterns of convergence and divergence. The stress concentration in the opening area is more dominant than the tension in the plate, as reported by previous research [12][13].



Sources: Author's Analysis Results.

Figure 7. Deformation at Model I and II

Figure 7 shows that rectangular-open plates have smaller deformations than other types. The percentage of plates with rectangular openings compared to plates without openings is 37.66%. Meanwhile, in model II, the plate with a square opening model has the smallest deformation compared to the plate without openings, which is in accordance with previous research [4][8], with a difference of 30.48%.

Support formation has also significantly influenced the stress concentration mechanism [14], where all supports (joints) on all four sides have a more even stress distribution [15]. In fixed supports, the lack of freedom of movement at the edges creates increased local deformation. Meanwhile, the restraint is removed at the edge in simply supported so the plate can move freely on the sides. This causes uniform deformation over the entire plate surface with lower peak values (especially for non-openings and rectangles) compared to fixed support. Pin supports make a significant contribution to the stiffness of the structure because all components can receive moments, vertical and horizontal forces so that the stress concentration is concentrated in the holes and support areas, which is more visible from dynamic tests

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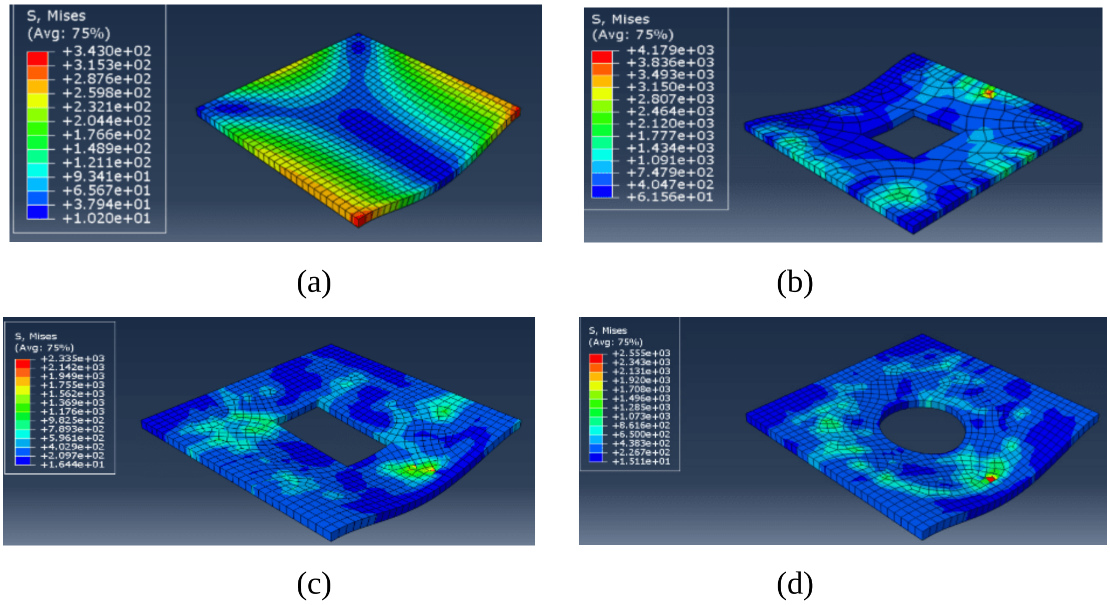
[16][17][18][19][20]. This very significant influence causes the stress distribution to become even in all areas considered outside the main supporting structure [21][22][23]. The type of bending damage following the type of support states that bending damage in plate structures depends on the type of support [4].

Plates without openings and with openings tend to have the same deformation pattern. The deformation has an even pattern in simple support, whereas, in fixed support, it is concentrated in the middle. Therefore, the opening does not influence the deformation pattern on a plate. However, the effectiveness of the opening geometry still needs to be considered because **Figure 7** shows evidence that the test objects have different maximum deformation values.

3.2 Model 3 and 4 (Fixed Support at 3 and 2 Opposite)

3.2.1 Stress



Sources: Author's Analysis Results.

Figure 8. Stress in Plate with Fixed Support at 3-sides; (a) Without Openings; (b) Square Openings; (c) Rectangular Openings; (d) Circular Openings

The stress distribution on a plate with fixed support on three sides shows that the side that does not have support tends to have high stress. This is because the flow of stress will lead to the side that has no support and will have maximum stress.

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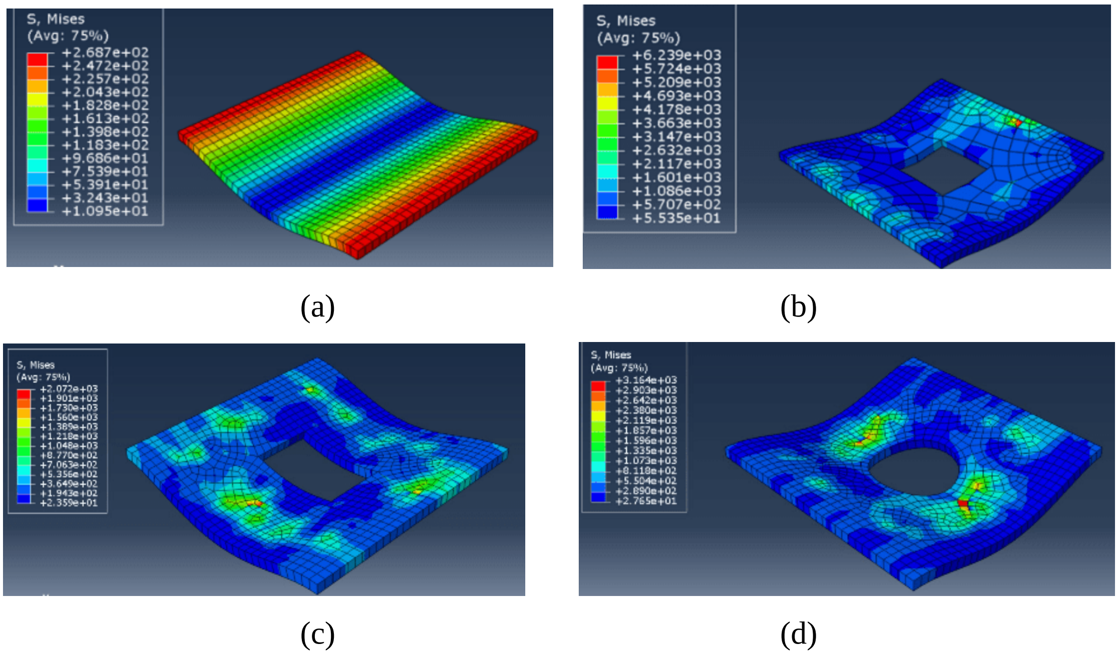
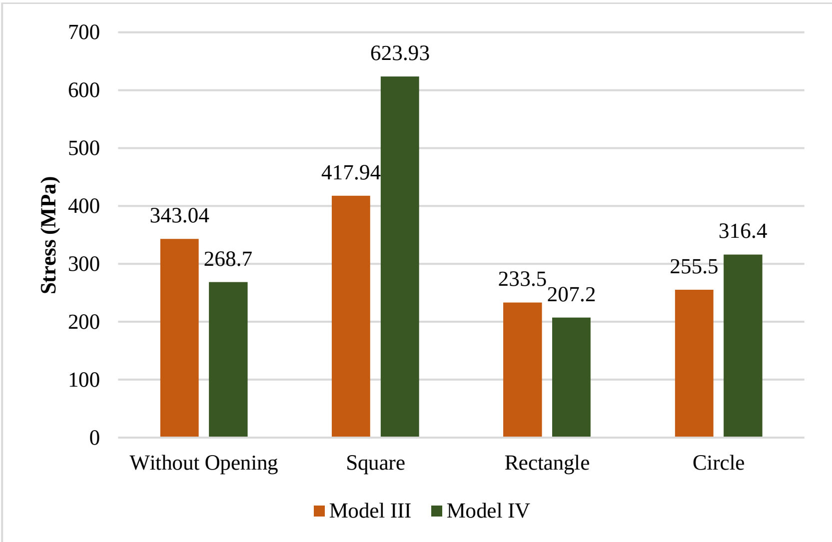


Sources: Author's Analysis Results.

Figure 9. Stress in Plate with Fixed Support at two opposite sides; (a) Without Openings; (b) Square Openings; (c) Rectangular Openings; (d) Circular Openings.

A plate with fixed support on two opposite sides without openings shows a fairly even stress distribution, with the center in the middle parallel to the side with the support. The stress distribution will increase as you move away from the center point, and the maximum stress is at the edge of the plate with support. Meanwhile, on plates with openings, the stress tends not to be at the edge of the plate but around the openings.



Sources: Author's Analysis Results.

Figure 10. Stress Model III and IV

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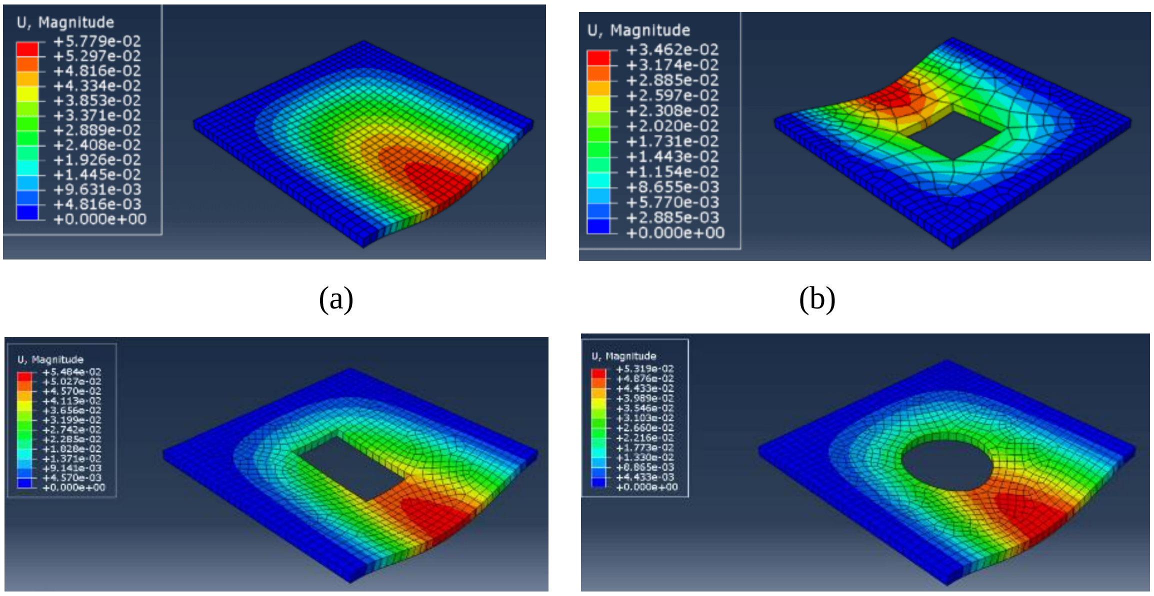
In models III and IV, openings in the square plate increase the stress by 21.84% and 132.21%, respectively, compared to plates without openings. The stress value is also influenced by differences in support formation on the plate, which causes stress concentration in the opening area [24][25].

The difference in stress values between fixed supports on three sides and two opposite sides of the plate can be explained through the principles of structural mechanics and the structure's response to loads. With support on three sides, the structure gains additional stability and stronger movement restrictions, resulting in a more even stress distribution across the surface. In contrast, fixed supports on two opposite sides make the structure more flexible, with the potential for more localized stress distribution, especially near the unsupported side.

3.2.2 Deformation



(a) (b)

(c) (d)

Sources: Author's Analysis Results.

Figure 11. Deformation in Plate with Fixed Support at 3-sides; (a) Without Openings; (b) Square Openings; (c) Rectangular Openings; (d) Circular Openings.

The deformation pattern of the fixed support plate on three sides shows the same results without and with openings. The deformation pattern leads to the edge of the plate, which has no support.

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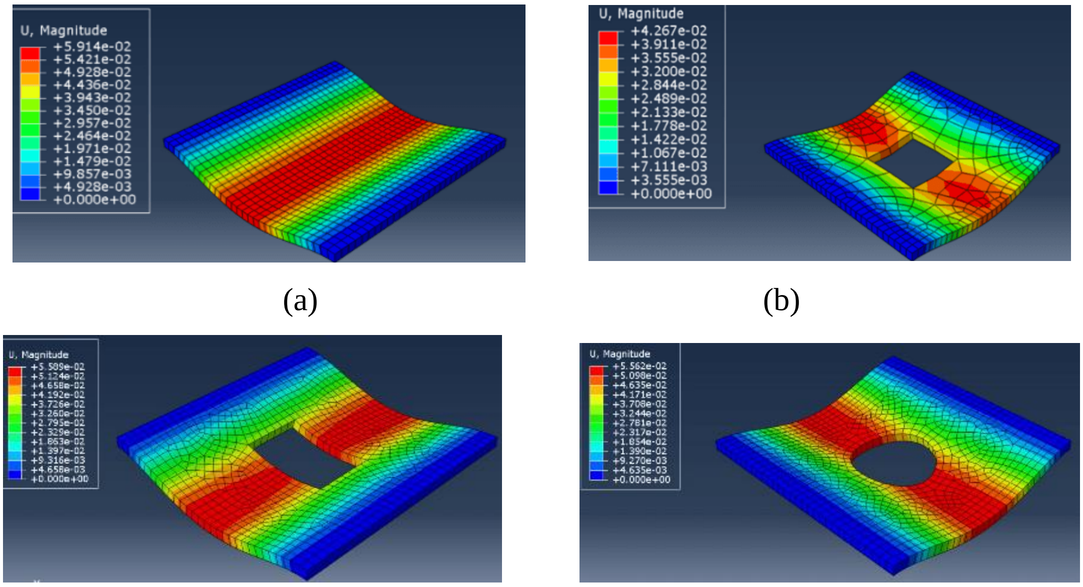
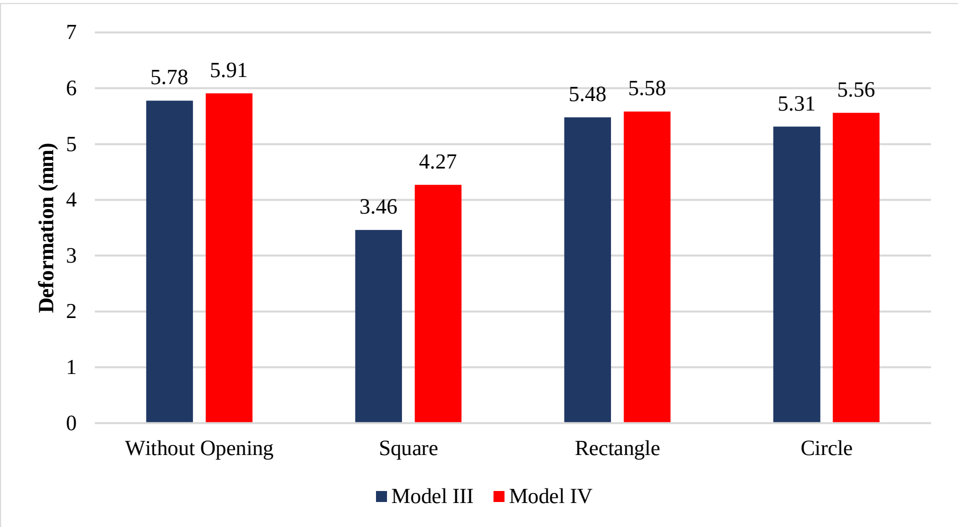


Sources: Author's Analysis Results.

Figure 12. Deformation in Plate with Fixed Support at two opposite sides; (a) Without Openings; (b) Square Openings; (c) Rectangular Openings; (d) Circular Openings.

The deformation pattern of the fixed support plate on two opposite sides shows the same results without openings or with openings. The deformation pattern becomes larger towards the center and parallel to the plate's side with support.



Sources: Author's Analysis Results.

Figure 13. Deformation Model III and IV

Furthermore, Model III and Model IV have deformation values of 66.91% and 38.62% compared to the reference model. This indicates that plates with openings will reduce the amount of deformation that occurs in the structure, reduce the stiffness value, and be effective

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in terms of material without reducing the main function of the structure that will be reviewed [2][4][8].

Fixed support on two opposite sides only provides support on two sides, which can result in greater deformation because the plate structure is more flexible in responding to loads. Meanwhile, fixed support on three sides provides support on three sides of the structure, which will limit movement. This leads to more controlled and even deformation throughout the structure. Based on this, plates with fixed support on three sides are more stable because they have more support points.

4. Conclusion

Openings in the plate can reduce the plate performance because they stress concentrations in the open areas. The stress concentration increases tend to be higher in rectangular openings, while square and circular openings are smaller than in plates without openings. In terms of deformation, the square-shaped openings have similar deformation values under all support conditions. Meanwhile, circular shapes tend to have high deformation values with fixed support on three and two opposite sides. However, the stress value at the circular opening can reduce the plate's stiffness by up to 50% by using a 4-sided fixed support. The type of support greatly influences the behavior of the plate due to uniform loading because the boundary conditions applied to the structure can cause the stress distribution formulation to change according to each boundary condition. The 4-sided fixed support has the greatest stress because the structure is clamped on all four sides, so the stress concentration behavior is focused on the open part. These findings emphasize the importance of considering variations in opening and the type of support in the plate in influencing structural performance and behavior. In this way, it is possible to optimize the design of appropriate types of supports and openings accordingly to reduce excess stress and improve the overall performance of the structure.

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References

[1] R. Feryanto and L. S. Tedianto, "Analisis Efek Bukaan Pada Waffle Slab Dengan Metode Elemen Hingga," *JMTS J. Mitra Tek. Sipil*, vol. 2, no. 3, p. 265, 2019, doi: 10.24912/jmts.v2i3.5838.

[2] A. S. Bora, D. G. Gaidhankar, and M. S. Kulkarni, "Analysis Of Flat Slab With And Without Opening," *Int. J. Sci. Technol. Res.*, vol. 8, no. 09, 2019.

[3] S. R. Ghogare, "Finite Element Analysis Of Flat Slab With And Without Opening," *IRJET*, 2020.

[4] P. Singh *et al.*, "Analisis Pengaruh Bentuk Bukaan Pada Pelat Lentur Dengan Metode Elemen Hingga," *JMTS J. Mitra Tek. Sipil*, vol. 5, no. 2, pp. 587–596, 2022.

[5] A. Shokoohfar, "A finite element analysis of slab opening effects on the column removal scenarios in large buildings," *ResearchGate*, no. April, 2023, doi: 10.22060/ajce.2023.21169.5795.

[6] D. E. Christopher *et al.*, "Bukaan Menggunakan Metode Elemen Hingga," *JMTS J. Mitra Tek. Sipil*, vol. 5, no. 2, pp. 555–564, 2022.

[7] E. S. Kalib and Y. W. Shewalul, "Response of the Flat Reinforced Concrete Floor Slab with Openings under Cyclic In-Plane Loading," *Hindawi Shock Vib.*, vol. 2021, 2021, doi: 10.1155/2021/2503475.

[8] S. T. Akkaya and R. Ghoroubi, "Experimental , analytical , and numerical investigation of punching behaviour of two-way rc slab with multiple openings," *Elsevier*, vol. 43, no. July, pp. 574–593, 2022, doi: 10.1016/j.istruc.2022.06.070.

[9] N. Garg, N. Das, B. G. Prusty, C. Song, and A. W. Phillips, "International Journal of Mechanical Sciences Modelling of laminated composite plates with weakly bonded interfaces using scaled boundary finite element method," *Int. J. Mech. Sci.*, vol. 170, no. November 2019, p. 105349, 2020, doi: 10.1016/j.ijmecsci.2019.105349.

[10] H. Abd El-Mottaleb, L. Abdel-Razek, M. Zaghlal, and R. EL-daly, "Effect of Openings on Multi-Panel Flat Slab With CFRP Bars: A Numerical Analysis," *Egypt. Int. J. Eng. Sci. Technol.*, vol. 40, no. 1, pp. 44–52, 2022, doi: 10.21608/eijest.2022.111609.1121.

[11] A. Faoji and K. A. Sambowo, "Perbandingan Tumpuan Jepit Dan Sendi Pada Struktur Power House Ditinjau Dari Segi Efisiensi Material Dan Biaya (Studi Kasus Proyek Pltmg Seram Peaker) (Comparison Of Fixed And Pinned On Structures Power House Is Reviewed From Material Efficiency And Costs," *J.Infras*, vol. 4, no. 2, pp. 119–126, 2019.

[12] S. S. Aman, B. S. Mohammed, M. A. Wahab, and A. Anwar, "Performance of reinforced concrete slab with opening strengthened using CFRP," *Fibers*, vol. 8, no. 4, 2020, doi: 10.3390/fib8040025.

[13] R. Nur Arini and R. Pradana, "Analisa Tegangan Regangan Pada Balok Dengan Menggunakan Software Abaqus Cae V6.14," *J. ARTESIS*, vol. 1, no. 2, pp. 193–198, 2021, doi: 10.35814/artesis.v1i2.3227.

[14] K. A. Ibrahim and M. H. Shukur, "Effect of openings on simply supported reinforced concrete skew slabs using fi nite element method," *De Gruyter*, 2023.

[15] B. S. Nasional, *Tata cara perencanaan ketahanan gempa untuk struktur bangunan gedung dan nongedung*, no. 8. 2019.

ISSN (*Online*) 2581-2157
F. Ma'arif / U Karst Vol 07 No. 02 Year 2023 ISSN (*Print*) 2502-9304

[16] U. B. Yesil and M. Engineering, "The Effect of Own Weight on Dynamic Analysis of a Pre-Stretched Composite Plate- Strip Containing Twin Circular Inclusions Under Bending Using Finite Element Method," *Acad. Platf. J. Eng. Sci.*, pp. 550–562, 2019, doi: 10.21541/apjes.488483.

[17] M. Nadaf and R. J. Fernandes, "Bending Analysis for Stress and Deflection for Cross-Ply Laminated Composite Plate Using Higher Order Shear Deformation Theory Subjected to Sinusoidal Loading using Finite," *INDIAN J. Sci. Technol. Res.*, pp. 7–9, 2023.

[18] R. Z. Al-rousan and B. R. Alnemrawi, "Punching shear code provisions examination against the creation of an opening in existed RC flat slab of various sizes and locations," *Elsevier*, vol. 49, no. January, pp. 875–888, 2023, doi: 10.1016/j.istruc.2023.02.007.

[19] D. Mosto, N. Jafarian, A. Naderi, and A. Mosto, "Effects of openings on the punching shear strength of reinforced concrete slabs," *Elsevier*, vol. 25, no. March, pp. 760–773, 2020, doi: 10.1016/j.istruc.2020.03.061.

[20] C. Methods *et al.*, "ScienceDirect Free vibration and transient dynamic response of functionally graded sandwich plates with power-law nonhomogeneity by the scaled boundary finite element method," *Elsevier*, vol. 376, p. 113665, 2021, doi: 10.1016/j.cma.2021.113665.

[21] M. Aminitabar, O. Kanaani, and A. R. Eskenati, "Numerical Evaluation of the Opening Effects on the Reinforced Concrete Slab Structural Performance," *Hindawi Shock Vib.*, vol. 2021, pp. 1–16, 2021, doi: 10.1155/2021/1060841.

[22] T. F. El-Shafiey, A. M. Atta, A. Hassan, and M. Elnasharty, "Effect of opening shape, size and location on the punching shear behaviour of RC flat slabs," *Elsevier*, vol. 44, no. August, pp. 1138–1151, 2022, doi: 10.1016/j.istruc.2022.08.076.

[23] P. Teknik and C. Commons, "Evaluation Of Structure Using Variety Of Slab Type Under Performance-Based Design: Case Study Common Working Space In Surabaya," *J. pensil*, vol. 12, pp. 196–206, 2023, doi: 10.21009/jpensil.v12i2.31492.

[24] O. Mohamed, R. Khattab, and N. Okasha, "Numerical Analysis of RC Slab with opening strengthened with CFRP Laminates Numerical Analysis of RC Slab with opening strengthened with CFRP Laminates," *IOP Conf. Ser. Mater. Sci. Eng.*, 2019, doi: 10.1088/1757-899X/603/4/042038.

[25] E. H. El-mawsly, K. Farouk, O. El-kashif, A. Adel, and H. Ahmed, "Case Studies in Construction Materials Experimental and numerical investigation on strengthening of RC flat slabs with central opening," *Elsevier*, vol. 16, no. December 2021, p. e00974, 2022, doi: 10.1016/j.cscm.2022.e00974.