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# Innovation of Precast Building Structures as an Alternative Solution for Fast and Strong Construction

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***ABSTRACT***
*Indonesia is recognized as one of the countries with the highest seismic vulnerability in the world, as it is located within the convergence zone of major tectonic plates. This condition creates an urgent need for buildings that are safe, efficient, and earthquake-resistant. One of the innovations that has been developed to address this demand is the application of precast building systems, which offer faster construction, higher quality consistency, and cost efficiency compared to conventional methods. This research aims to analyze the structural performance of a two-story precast house, specifically the Rumah Sistem Panel Instan (RUSPIN), with a focus on strength, stability, and resistance to seismic loads. The methodology involves numerical modeling based on the Finite Element Method (FEM), utilizing ETABS software for global structural analysis and Abaqus for detailed element analysis, particularly at the beam–column joints. The materials employed include concrete with a compressive strength of Fc 25 MPa (K-300) and reinforcing steel BJTP 280 MPa. Variations of precast elements such as L, T, and cross-shaped columns, as well as single and double beams, were modeled. Key parameters analyzed include the fundamental period of the structure, inter-story drift, internal forces, stresses, strains, and the capacity of A325 bolt connections. The results indicate that the natural period of vibration falls within the safe range, with Tmin 0.233 seconds, Tmax 0.327 seconds, and Tprogram 0.301 seconds. Maximum displacements in both X and Y directions were 0.03 mm, significantly below the allowable limit of 120 mm, demonstrating structural stability and compliance with serviceability requirements. Internal force analysis confirmed that columns predominantly carried axial loads, while beams resisted bending moments and shear forces. Detailed Abaqus simulations further showed that stresses, strains, and deformations remained within the elastic limits of the materials, while bolt connections provided capacities exceeding the design forces. In conclusion, the two-story precast system demonstrates reliable performance under both gravity and seismic loads. This system can therefore be considered a viable alternative for efficient, strong, and rapid construction in disaster-prone regions, while also supporting the advancement of sustainable building technologies in Indonesia.*
***KEYWORDS:*** *Abaqus, Earthquake resistant building, Etabs, Finite Element Method, Instant Panel System House (RUSPIN), Precast Structure.*

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## I. INTRODUCTION

Indonesia is located in a complex zone of interaction between several major tectonic plates such as the Indo-Australian, Eurasian, Pacific, and Philippine Sea plates, making it one of the most seismically active regions in the world as it lies within the Ring of Fire.(Mukesh et al. 2024). This condition further emphasizes the importance of planning and designing buildings that are responsive to local geological characteristics, as demonstrated by the significant impacts of the earthquakes in Palu and Lombok (Setyonegoro et al. 2024).

Many buildings in Indonesia are designed based on outdated standards that insufficiently consider seismic loads and lateral resistance systems. (Imran, Siringoringo, and Rainayana 2024). The demand for decent and safe housing continues to increase along with population growth and urbanization. Vertical housing offers an effective solution to meet this demand by utilizing precast technology for earthquake-resistant and energy-efficient designs. The concept of near zero energy buildings (nZEB) or buildings with nearly zero energy consumption is highly relevant, where structures are not only designed to withstand earthquakes but also to be efficient in energy use by harnessing renewable energy sources (Koca 2023).

To support this efficiency, precast technology emerges as an alternative construction method that is fast, precise, and economical. Precast building components are fabricated and assembled on-site, offering more controlled quality and shorter construction duration compared to conventional methods. In addition, precast elements can be specifically designed to meet earthquake resistance standards, making them an appropriate solution for the development of vertical housing in disaster-prone areas. (Palupi, Lumbu, and Rumbayan 2024).

This research aims to analyze the structural performance of the two-story RUSPIN precast house using the Finite Element Method (FEM). The analysis is conducted by utilizing data from the two-story precast house as a reference, in order to obtain a deeper understanding of the structural behavior of the precast building. Through FEM modeling, this study is expected to provide a comprehensive overview of the capacity, safety, and efficiency of the two-story precast house structure, as well as serve as a scientific basis for the development of adaptive precast designs that are resistant to potential seismic loads and other hazards, particularly in vulnerable areas such as Kendal Regency, Central Java.

Thus, this research is expected to contribute to the development of precast technology in Indonesia while also supporting the improvement of housing infrastructure resilience against natural disasters.

## II. METHOD

This study employs a quantitative approach with a descriptive-analytical method to analyze the capacity of structural elements in a three-story precast house using the Finite Element Method (FEM). The global structural modeling is carried out using ETABS software, while the internal forces in the column and beam elements are further analyzed with Abaqus. The results of both analyses are compared to evaluate the reliability and performance of the three-story precast house structure as a basis for developing safer and more efficient designs.

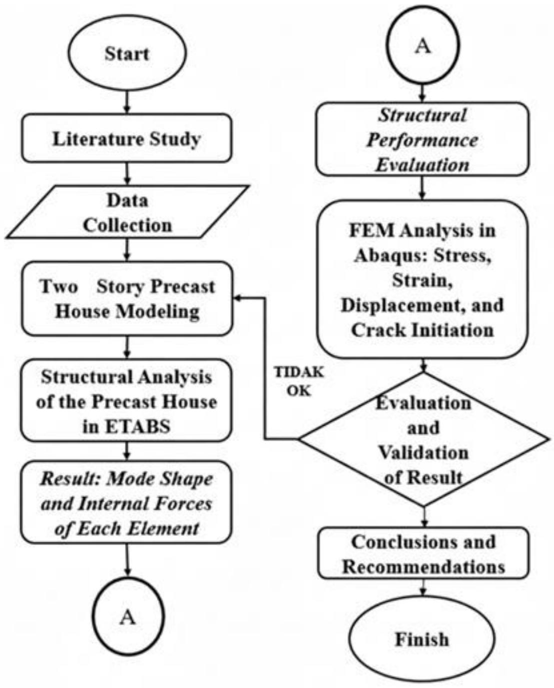
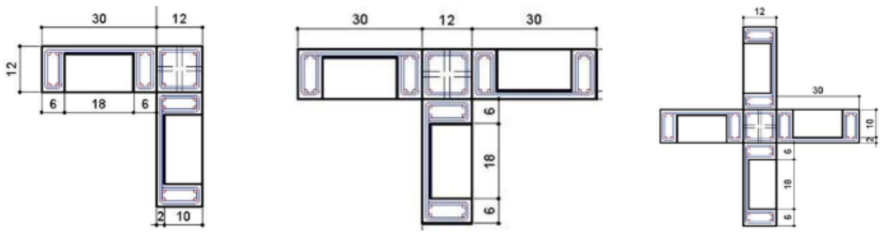



**Figure 1.** Flowchart

The data used in the planning of the 12 cm panel precast house include project information, concrete materials, and reinforcement steel. The project is located at Jl. Jetis, Margosari, Limbangan District, Kendal Regency, serving as a two-story residential building. The structure is designed using concrete with a strength of Fc 25 MPa (K300), a unit weight of 2400 kg/m³, and a modulus of elasticity of 23,500 MPa, as well as BJTP 280 reinforcement steel with a yield strength of 280 MPa, ultimate strength of 405 MPa, and modulus of elasticity of 200,000 MPa. These specifications serve as the basis for the modeling and analysis of the precast structure.

**Column Dimension**

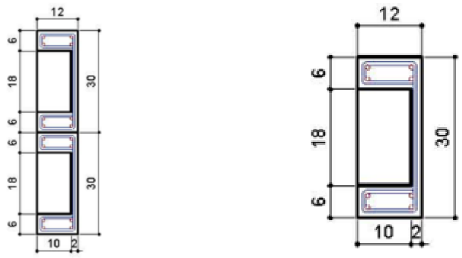



**(2a)** Column L **(2b)** Column T **(2c)** Column +

**Figure 2.** Column Dimension

Column dimensions in the precast structure are designed according to specific requirements. L-shaped columns have a cross-sectional area of 0.054 m², T-shaped columns 0.0738 m², and +-shaped columns 0.0936 m². These variations in dimensions ensure the strength and stability of the building according to the structural function of each column.

**Beam Dimension**



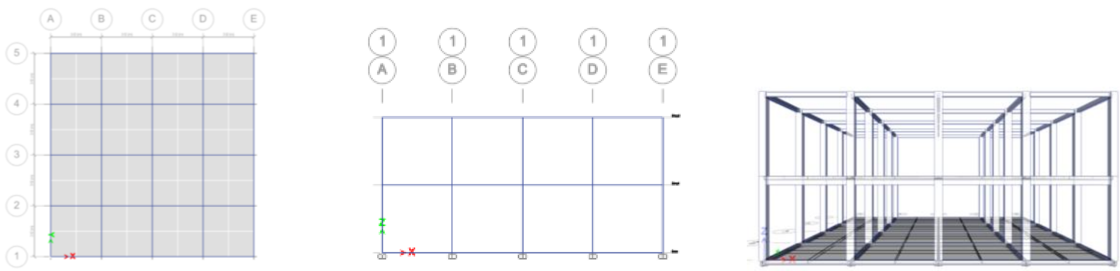

**(3a)** Double Beam **(3b)** Single Beam

**Figure 3.** Beam Dimension

Beams in the precast structure are designed with two types of cross-sections. Double beams have a cross-sectional area of 0.0396 m², while single beams have a cross-sectional area of 0.0198 m². These dimensions are adjusted to meet the requirements for structural strength and efficiency.

## III. RESULTS AND DISCUSSION

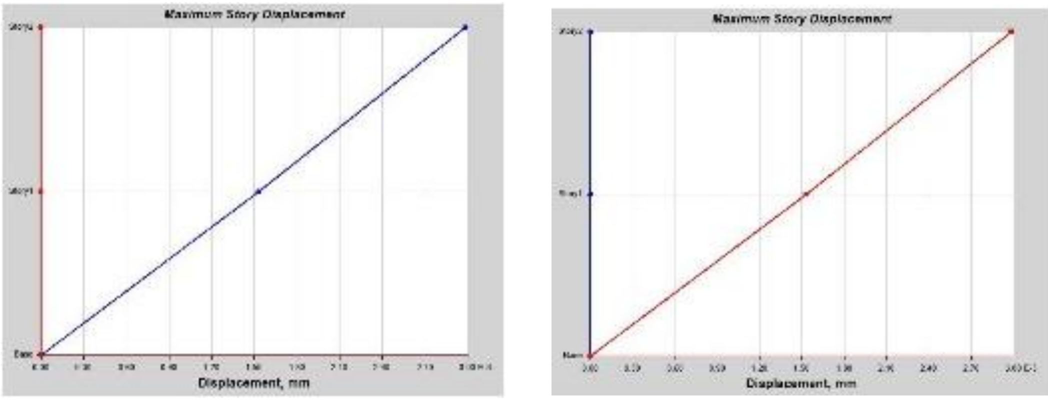
**Precast Modeling Using ETABS**



**(4a)** Plan **(4b)** Modeling 2D **(4c)** Modeling 3D

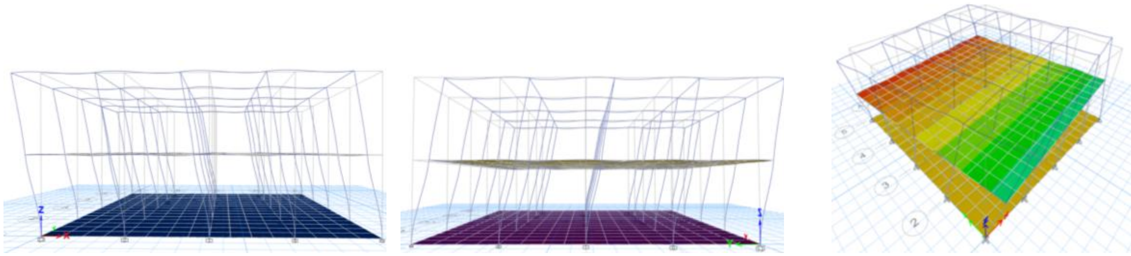
**Figure 4.** Precast Modeling in ETABS

The structural analysis results using ETABS software indicate that the fundamental period of the planned structure has a minimum value (Tmin) of 0.233 seconds, a maximum value (Tmax) of 0.327 seconds, and a program period (Tprogram) of 0.301 seconds. These values are still within the allowable range, indicating that the structure has appropriate stiffness and dynamic stability according to design criteria. Additionally, the inter-story drift evaluation shows that the maximum drift in both the X and Y directions reaches only 0.03 mm, which is far below the permissible inter-story drift of 120 mm. This demonstrates that the analyzed building structure not only meets serviceability limit requirements but is also safe and stable under lateral loads, and can therefore be considered structurally adequate.




**(5a)** Max Displacement X **(5b)** Max Displacement Y

**Figure 5.** Maximum Displacement of the Precast Structure



**(6a)** Mode Shape 1 **(6b)** Mode Shape 2 **(6c)** Mode Shape 3

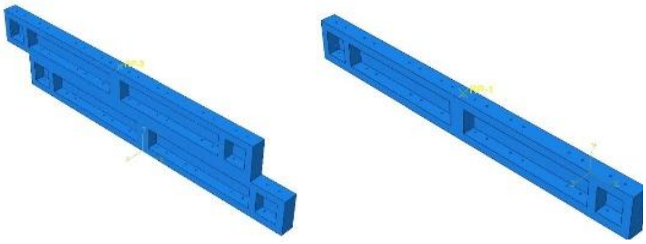
**Figure 6.** Mode Shape and Modal Participation Ratio

| **Internal Forces in the Precast House Structure** | | | | | |
|---|---|---|---|---|---|
| **Internal Force** | **Column L** | **Column T** | **Column +** | **Double Beam** | **Single Beam** |
| Axial Force (kN) | 20.993 | -38.632 | -69.300 | - | -1.0515 |
| Moment Force (kN/m) | M2= 2.178 | M2= 4.654 | M2 =-0.897 | 6.142 | -2.092 |
| | M3= 2.178 | M3= 0.549 | M3= 0.5591 | | |
| Shear Force (kN) | V2= -0.802 | V2 =-0.1977 | V2= -0.523 | 15.116 | 4.8155 |
| | V3= -0.802 | V3 = -1.711 | V3= -0.322 | | |
| Torsion Force (kN/m) | - | - | | 0.0641 | -0.0003 |

Based on the internal force analysis using ETABS software, a varied distribution of forces was observed in the column and beam elements. L-shaped columns resist an axial force of 20.993 kN, with bending moments M2 and M3 of 2.178 kN·m each, and shear forces V2 and V3 of –0.802 kN. KT columns experience a compressive axial force of –38.632 kN, with moments M2 = 4.654 kN·m and M3 = 0.549 kN·m, and shear forces V2 = –0.1977 kN and V3 = –1.711 kN. In K+ columns, a larger axial force of –69.300 kN is recorded, with moments M2 = –0.897 kN·m and M3 = –0.5591 kN·m, and shear forces V2 = –0.523 kN and V3 = –0.322 kN. Meanwhile, double beams resist a bending moment of 6.142 kN·m, shear force of 15.116 kN, and torsion of 0.0641 kN·m. Single beams show a compressive axial force of –1.05 kN, bending moment –2.092 kN·m, shear force 4.8155 kN, and torsion –0.00356 kN·m. These results indicate that each structural element functions according to its role in bearing loads, with columns primarily resisting axial forces, while beams mainly resist bending moments and shear forces. The findings provide a comprehensive overview of the internal force performance of structural elements, which is essential for evaluating the overall capacity and stability of the building system.

**Precast Modeling Using Abaqus**

**(7a)** Column L **(7b)** Column T **(7c)** Column +

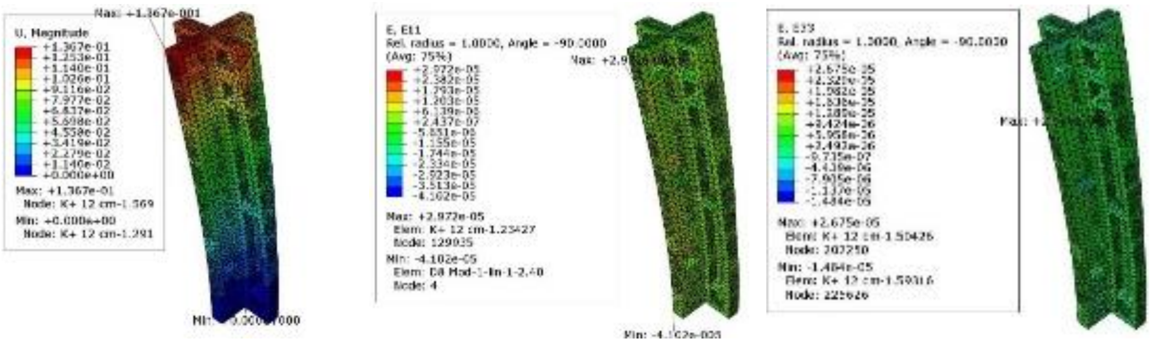


**(7d)** Beam 2 **(7e)** Beam 1

**Figure 7.** Modeling of Precast House Structural Elements in Abaqus

**Analysis Results of Precast Column Elements +**

Calculation of the +-shaped column Element in the precast house with 12 cm thick panels is based on the maximum internal forces from the ETABS program analysis.



**(8a)** Displacement Max **(8b)** Strain X **(8c)** Strain Y

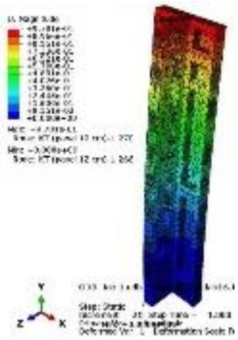
**(8d)** Stress X **(8e)** Stress Y

**Figure 8.** Analysis Results of Precast Elements K+

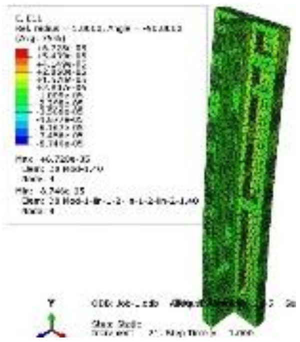
Based on the numerical analysis using ABAQUS software on the column model, the structure demonstrates adequate performance in resisting the applied loads. The maximum displacement is recorded at 0.1367 mm, indicating very small deformation and still within the elastic limit. Strains in the X and Y directions are 0.00004102 and 0.0000267, respectively, showing that the column does not experience significant deformation. Maximum stresses in the X and Y directions are 8.204 MPa and 0.692 MPa, well below the material capacity of the column. Overall, these results confirm that the column can perform effectively under the analyzed loading conditions, without any indication of damage or structural failure.

**Analysis Results of Precast Column Elements**

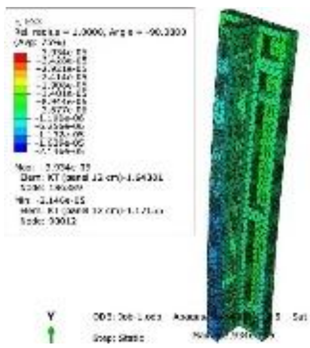
Calculation of the T-shaped column element in the precast house with 12 cm thick panels is based on the maximum internal forces from the ETABS program analysis.



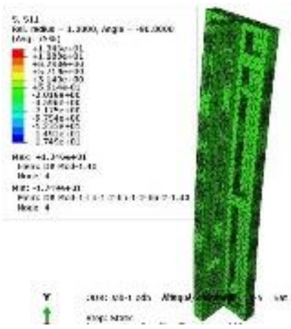
**(9a)** Displacement Max



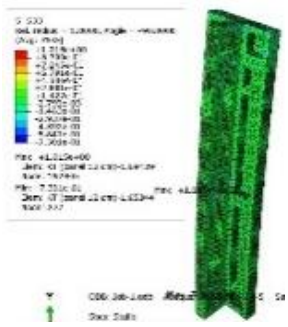
**(9b)** Strain X



**(9c)** Strain Y



**(9d)** Stress X



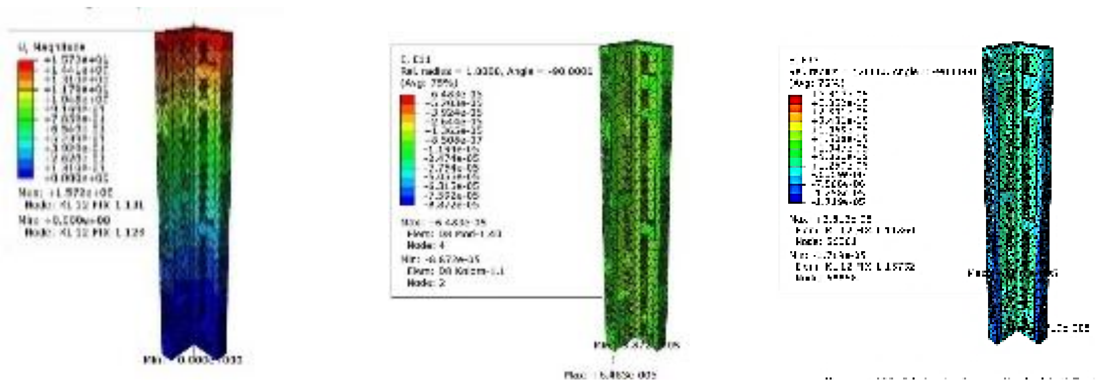
**(9e)** Stress Y

**Figure 9.** Analysis Results of Precast Elements KT

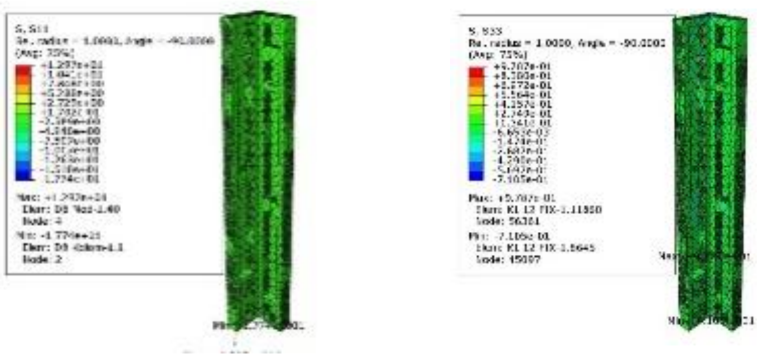
Based on the analysis conducted using ABAQUS software on the column model, the results indicate good structural performance. The maximum displacement observed is 0.978 mm, showing that the column undergoes minimal deformation and remains within the elastic limit. Strains in the X and Y directions are 0.00008746 and 0.00003934, respectively, indicating very small deformations. The stresses in the X and Y directions are 17.49 MPa and 1.015 MPa, respectively, which are within the safe limits of the column material. Overall, this analysis demonstrates that the column can effectively resist the applied loads without any signs of damage or structural failure, maintaining its functional performance under the tested conditions.

**Analysis Results of Precast Column L Elements**

Calculation of T-shaped column Element in the precast house with 12 cm thick panels is based on the maximum internal forces from the ETABS program analysis.



**(10a)** Displacement Max **(10b)** Strain X **(10c)** Strain Y



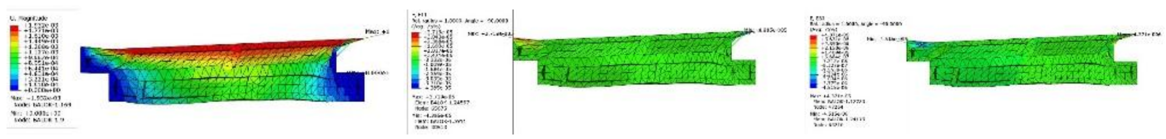
**(10d)** Stress X **(10e)** Stress Y

**Figure 10.** Analysis Results of Precast Elements KL

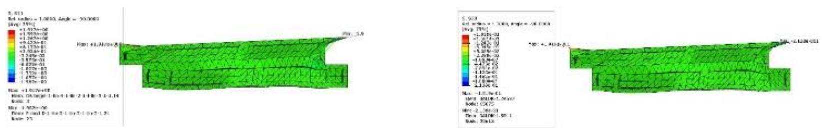
Based on the analysis conducted using ABAQUS software on the column model, the results indicate good structural performance. The maximum displacement observed is 1.572 mm, showing that the column undergoes minor deformation and remains within the elastic limit. Strains in the X and Y directions are 0.00008872 and 0.00003813, respectively, indicating that the deformations are very minimal. The stresses in the X and Y directions are 17.74 MPa and 0.9787 MPa, respectively, which are still within the safe limits of the column material. Overall, this analysis demonstrates that the column can effectively resist the applied loads without any signs of damage or structural failure, maintaining its functional performance under the tested conditions.

**Analysis Results of Double Beam Elements**

Calculation of the beam connection with dimensions 300 mm × 132 mm in the precast house with 12 cm thick panels is based on the maximum internal forces from the ETABS program analysis.



**(11a)** Displacement Max **(11b)** Strain X **(11c)** Strain Y



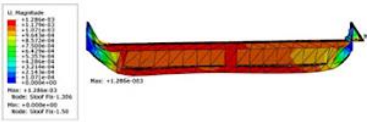
**(11d)** Stress X **(11e)** Stress Y

**Figure 11.** Analysis Results of Precast Elements Double Beams

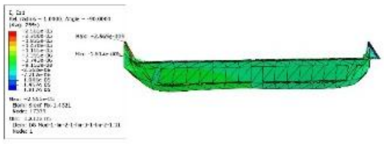
Based on the analysis conducted using ABAQUS software on the column model, the results indicate good structural performance. The maximum displacement observed is 0.001932 mm, showing that the column undergoes very small deformation and remains within the elastic limit. Strains in the X and Y directions are 0.00003719 and 0.00004515, respectively, indicating minimal deformation. The stresses in the X and Y directions are 1.91 MPa and 0.213 MPa, respectively, which are still within the safe limits of the column material. Overall, this analysis demonstrates that the column can effectively resist the applied loads without any signs of damage or structural failure, maintaining its functional performance under the tested conditions.

**Analysis Results of Single Beam Elements**

Calculation of the beam connection with dimensions 132 mm × 132 mm in the precast house with 12 cm thick panels is based on the maximum internal forces from the ETABS program analysis.

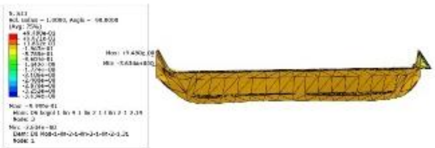


**(12a)** Displacement Max



**(12b)** Strain X

**(12c)** Strain Y



**(12d)** Stress X

**(12e)** Stress Y

**Figure 12.** Analysis Results of Precast Elements Single Beams

Based on the analysis conducted using ABAQUS software on the column model, the results indicate good structural performance. The maximum displacement observed is 0.001286 mm, showing that the column undergoes very minimal deformation and remains within the elastic limit. Strains in the X and Y directions are 0.00002585 and 0.00000694, respectively, indicating that the deformations are negligible. The stresses in the X and Y directions are 3.63 MPa and 0.909 MPa, respectively, which are still within the safe limits of the column material. Overall, this analysis demonstrates that the column can effectively resist the applied loads without any signs of damage or structural failure, maintaining its functional performance under the tested conditions.

Results should be clear and concise, and be part of a single section, discussing the significance of the results of the work, not repeat them. Extensive citation and discussion of the published literature should be avoided.

## IV. CONCLUSION

Based on the results of the study on the two-story precast house innovation, it can be concluded that the internal force analysis on the structural elements of columns and beams shows that the load distribution can be properly carried by the precast structure, where in column K+ the axial force reaches -69.3 kN with bending moments M2 of 0.8977 kNm and M3 of -0.5591 kNm as well as shear forces V2 of -1.7118 kN and V3 of -0.1977 kN, in column KT the axial force is -38.63 kN with bending moments M2 of 0.5496 kNm and M3 of 4.6547 kNm and shear forces V2 of -1.7118 kN and V3 of -0.1977 kN, in column KL the axial force is -20.9934 kN with bending moments M2 of -1.3735 kNm and M3 of 2.1781 kNm and shear forces V2 of -0.8027 kN and V3 of 1.2748 kN, while in the precast beam the axial force is 0 kN, the bending moment M3 is 6.1428 kNm, the shear force V2 is 15.1167 kN, and the torsion is 0.0715 kNm; the two-story precast structure also demonstrates a good dynamic response to seismic loads with a displacement of only 0.003 mm in both the x and y directions and a natural vibration period of 0.302 seconds, which is still below the maximum allowable structural period of 0.471 seconds according to the specified seismic location; furthermore, in column K+, the compressive capacity of eight A325 bolts reaching 379,814.4 kN and the shear capacity of 219,285.94 kN are both far greater than the design axial and shear forces of -69.3 kN and 0.5235 kN, respectively, indicating that the connection is safe, while in column KT with six A325 bolts, the compressive capacity of 284,860.8 kN exceeds the design axial force of -38.63 kN and the shear capacity of 164,464.44 kN surpasses the design shear force of -1.7118 kN, confirming that this connection is safe; similarly, in column KL with four A325 bolts, the compressive capacity of 189,907.2 kN and the shear capacity of 109,642.96 kN are greater than the design axial and shear forces of -20.9934 kN and 1.2748 kN, respectively, and in the precast beam with four A325 bolts, the compressive and shear capacities of 189,907.2 kN and 109,642.96 kN also exceed the design axial and shear forces of 0 kN and 15.1167 kN, respectively, confirming that the beam connection is safe; overall, the analyzed two-story precast structure demonstrates adequate performance in resisting both gravity and seismic loads, and based on the internal force distribution, displacement, and connection strength analysis, the structure is considered safe and capable of maintaining its integrity, thereby confirming that precast technology is an effective and efficient alternative solution for building construction in earthquake-prone areas due to its advantages in construction speed and sufficient structural strength.

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