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Journal of Civil Engineering Science

(E-ISSN: XXXXX)

Vol. 1, No. 1, May, 2026

Structural Analysis of a Five-Storey Reinforced Concrete Hospital Building: A Case Study of RSI NU Cakra Medika

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Received 20 January 2026; Revised 02 February 2026; Accepted 26 February 2026; Published 1 May 2026

Abstract

The construction of hospital buildings requires a high level of structural safety, reliability, and compliance with current design standards. This study presents a reanalysis of the structural design of the RSI NU Cakra Medika building, which was originally designed based on earlier regulations, to evaluate its conformity with the latest Indonesian concrete design standard, SNI 2847:2019. The reanalysis was conducted by collecting existing design documents, including structural drawings, calculation reports, and material specifications. A three-dimensional finite element model was developed using structural analysis software to evaluate the building's response to gravity and seismic loads in accordance with the updated code requirements. The results indicate that several structural elements, particularly beams and columns, require dimensional adjustments or higher-strength materials to satisfy strength and serviceability criteria under the current standard. Furthermore, improvements in the seismic force–resisting system configuration are necessary to enhance the building's lateral load resistance. The findings demonstrate the importance of reassessing existing structural designs using updated standards to ensure the safety and performance of hospital buildings and provide a useful reference for similar reanalysis projects.

Keywords: Reinforced concrete structure; Structural reanalysis; Hospital building; Seismic analysis; Finite element method

1. Introduction

Infrastructure development plays a crucial role in supporting socio-economic growth and improving public welfare[1,2]. Among various types of infrastructure, healthcare facilities hold a particularly important position, as they directly affect the quality of life and resilience of society. Hospitals are expected to remain functional not only under normal operating conditions but also during extreme events, such as earthquakes. Therefore, hospital buildings must be designed with a high level of structural safety, reliability, and compliance with current design standards to ensure continuous healthcare services for the community[3]. Reinforced concrete is widely used in hospital construction due to its strength, durability, and adaptability[4]. Structural components such as foundations, beams, columns, floor slabs, and roof slabs are required to resist both vertical loads caused by gravity and horizontal loads induced by seismic actions. While increasing member dimensions is often associated with higher structural capacity, overly conservative sizing may

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lead to inefficient and uneconomical designs, particularly in multi-storey buildings[5,6]. Structural elements that carry the largest load demands, such as beams and columns, therefore require careful analysis to determine optimal cross-sectional dimensions that satisfy both strength and serviceability requirements[5,7]. In Indonesia, many hospital buildings were designed using structural standards that have since been revised. Updates in design codes, especially those related to concrete behavior and seismic resistance, may significantly affect the adequacy of existing structural designs. However, in practice, buildings that were designed under older regulations are often assumed to remain adequate without systematic reassessment[8].

This situation raises concerns regarding the structural performance and regulatory compliance of essential facilities, such as hospitals, when evaluated using the latest standards. In particular, limited attention has been given to the reanalysis of existing hospital structures to identify whether adjustments in member dimensions, material strength, or seismic force–resisting systems are required. Based on this background, a clear research gap exists in the form of limited case studies that explicitly examine how updated concrete design standards influence the safety and performance of existing hospital buildings. There is a lack of practical references that demonstrate the process of reassessing reinforced concrete structures originally designed under older codes and evaluating their compliance with current regulations.

To address this gap, this study presents a reanalysis of the reinforced concrete structural design of the RSI NU Cakra Medika Hospital building located in Mayong, Jepara Regency. The building is designed as a five-storey structure with a basement, which necessitates careful evaluation of its response to gravity and seismic loads. The reanalysis is conducted based on the latest Indonesian concrete design standard, SNI 2847:2019, using a three-dimensional finite element model. The study focuses on evaluating the adequacy of structural elements, identifying components that require modification, and assessing the effectiveness of the seismic force–resisting system. The findings of this study are expected to contribute practical insights for engineers and stakeholders in reassessing existing hospital buildings and provide a useful reference for similar projects aimed at aligning structural designs with updated regulations.

2. Material and Methods

This study employed a quantitative engineering approach to reanalyses the structural design of a five-storey reinforced concrete hospital building based on the latest Indonesian concrete design standard, SNI 2847:2019. The research stages were structured to systematically evaluate the adequacy of the existing structural design under updated gravity and seismic loading requirements and to identify necessary modifications to ensure safety and regulatory compliance

2.1. Research Object and Data Collection

The research object is the RSI NU Cakra Medika Hospital building, located in Mayong, Jepara Regency, Indonesia, as illustrated in Figure 1. The structure is a multi-storey reinforced concrete building comprising five above-ground storeys and one basement level. As a healthcare facility, the building is required to meet stringent structural performance criteria, particularly in terms of safety, serviceability, and durability, given its continuous operation, high occupancy, and critical post-disaster functionality. The hospital accommodates various medical services and supporting facilities, resulting in complex load demands, including dead loads from structural and non-structural components, live loads associated with medical equipment and patient occupancy, and environmental loads in accordance with applicable design standards. Consequently, a high level of structural reliability and compliance with national building codes is essential. Data used in this study were obtained from comprehensive existing design documentation provided by the project stakeholders. These documents include architectural drawings, structural drawings, structural calculation reports, and detailed material specifications. Collectively, they provide essential information on building geometry, structural configuration, load assumptions, member dimensions, reinforcement detailing, and material properties adopted in the original design. The use of as-built design documents ensures that the analysis accurately reflects the actual structural system and design intent, thereby enhancing the validity and practical relevance of the research findings.

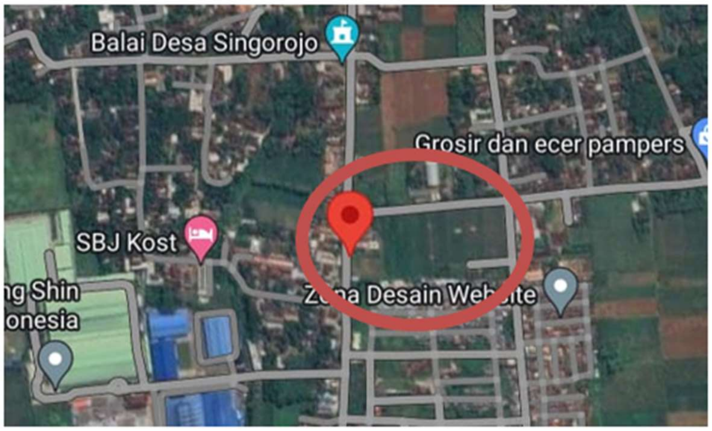

Figure 1. Location of the study

2.2. Structural Modeling and Loading

A three-dimensional structural model of the building was developed using ETABS, a finite element–based structural analysis software[9,10], to accurately represent the actual structural behavior. Beams and columns were modeled as frame elements, while slabs were modeled as shell elements[7,11]. Material properties for concrete and reinforcing steel were defined according to the requirements specified in SNI 2847:2019.

The applied loads consisted of dead loads, live loads, and seismic loads. Dead loads included the self-weight of structural components and permanent non-structural elements, while live loads were assigned based on the functional use of hospital buildings. Seismic loads were determined in accordance with the relevant Indonesian seismic design provisions (RSA Cipta Karya), considering the building's location, site conditions, and importance category as illustrated in Figure 2. Load combinations were applied following SNI 2847:2019 to obtain critical internal forces and structural responses.

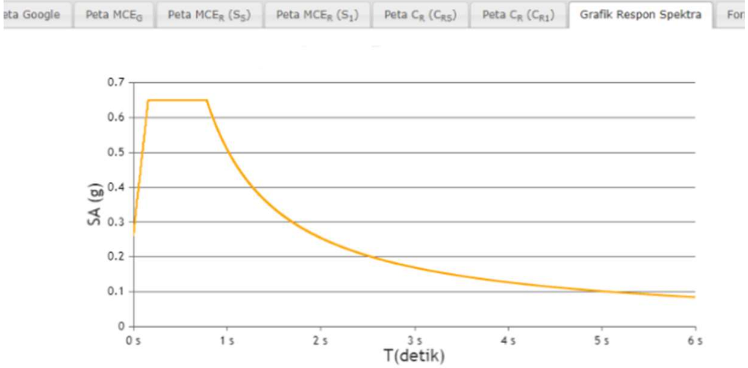

Figure 2. Spectrum response for Jepara area

2.3. Reanalysis Procedure

The reanalysis was conducted by evaluating internal forces, including axial forces, bending moments, and shear forces, obtained from the structural model under the governing load combinations. These forces were used to reassess the capacity of the main structural elements, such as beams, columns, slabs, stairs, and foundations, based on the strength and serviceability criteria specified in SNI 2847:2019. Particular attention was given to columns and beams, as these elements play a dominant role in resisting gravity and seismic loads. The adequacy of the seismic force–resisting system was also evaluated by examining the overall structural response under lateral loading. Structural elements that did not satisfy the code requirements were identified, and appropriate recommendations, such as dimensional adjustments or the use of higher-strength materials, were proposed.

2.4. Evaluation Criteria and Output

Structural performance was evaluated by comparing the demand–capacity ratios of each structural element with the allowable limits defined in SNI 2847:2019. Compliance with strength and serviceability requirements was used as the primary criterion for assessing structural adequacy. The outputs of this study include an assessment of the conformity of the existing structural design with current standards, identification of elements requiring modification, and recommendations to improve the overall safety and performance of the hospital building.

3. Results and Discussion

3.1. Analysis Data

The technical analysis data indicate that the building under study is a hospital facility consisting of five storeys. The building has a length of 24 m and a width of 32 m, with an inter-storey height of 4.2 m. As a healthcare facility, the structure is required to meet high safety standards against both gravity and lateral loads. The material properties used in the analysis consist of reinforced concrete with a specified compressive strength (f'c) of 30 MPa. Deformed reinforcing steel has a yield strength (fy) of 420 MPa, while plain reinforcing steel has a yield strength of 280 MPa. The modulus of elasticity of concrete and steel are 25,742.96 MPa and 200,000 MPa, respectively. Structural loading includes dead loads, live loads, wind loads, and seismic loads in accordance with applicable design standards. These parameters form the basis for the structural analysis and design of the main building elements.

3.2. Roof Slab Analysis

The roof slab was designed with a thickness of 12 cm using 12 mm diameter reinforcement. The analysis results show that the maximum bending moment in the X-direction is 6.636 kN·m at the support and 3.143 kN·m at midspan. In the Y-direction, the maximum bending moment is 4.977 kN·m at the support and 1.484 kN·m at midspan. Based on these results, reinforcement Ø12–100 mm was provided at the supports and Ø12–150 mm at midspan in the X-direction, while Ø12–150 mm at the supports and Ø12–200 mm at midspan were used in the Y-direction. These reinforcement arrangements indicate that the roof slab satisfies the required flexural capacity in an efficient and safe manner.

3.3. Floor Slab Analysis

The floor slab was designed with a thickness of 14 cm using Ø12 mm reinforcement. The maximum bending moment in the X-direction is 10.605 kN·m at the support and 5.023 kN·m at midspan. In the Y-direction, the corresponding moments are 7.954 kN·m at the support and 2.372 kN·m at midspan. Based on the analysis, Ø12–150 mm reinforcement was applied in the X-direction and Ø12–200 mm in the Y-direction. Compared to the roof slab, the floor slab experiences higher bending moments due to larger live loads, requiring greater slab thickness and reinforcement to meet strength and serviceability requirements.

3.4. Beam Analysis

As described in Table 1, the structural system consists of main beams and secondary beams with varying dimensions. Main beam B1 has a cross-section of 35 × 70 cm, while main beam B2 measures 25 × 50 cm. Secondary beams BA1 and BA2 have dimensions of 30 × 55 cm and 15 × 30 cm, respectively. The analysis results indicate that main beams require greater flexural reinforcement than secondary beams due to higher load demands. Reinforcement at support and midspan regions was proportioned to ensure adequate flexural capacity and safe force distribution within the structural frame system.

Table 1. Summary of beam reinforcement

Beam Type	Dimensions (cm)	Flexural Reinforcement at Support	Flexural Reinforcement at Midspan
B1	35 x 70	3D19	4D19
B2	25 x 50	2D19	3D19
BA1	30 x 55	3D16	4D16
BA2	15 x 30	2D16	3D16

3.5. Column Analysis

Two column types were designed, namely column K1 with dimensions of 70 × 70 cm and column K2 with dimensions of 50 × 50 cm. A concrete cover of 40 mm was applied. The main reinforcement uses 19 mm diameter bars, while the transverse reinforcement employs 10 mm diameter stirrups (see Table 2). Column K1 requires 21D19 with Ø10–300 mm stirrups, whereas column K2 uses 11D19 with Ø10–200 mm stirrups. These differences reflect the variation in axial forces and bending moments acting on the columns, ensuring adequate load-carrying capacity and structural stability.

Table 2. Summary of column reinforcement

Column Type	Dimensions (cm)	Longitudinal Reinforcement (mm)	Transverse Reinforcement (Stirrups) (mm)
K1	70 x 70	21D19	Ø10-300

K2	50 x 50	11D19	Ø10-200

3.6. Ramp Analysis

The ramp structure was designed using concrete with a compressive strength of 30 MPa and Ø12 mm reinforcement. The maximum bending moments in the X-direction are 9.241 kN·m at the support and 4.949 kN·m at midspan. In the Y-direction, the corresponding moments are 10.172 kN·m and 5.627 kN·m, respectively. Based on these results, Ø12–150 mm reinforcement was applied in the X-direction and Ø12–200 mm in the Y-direction. These results indicate that the ramp requires careful consideration of combined loads due to its inclination and traffic loads.

3.7. Stair Analysis

The stair has a total length of 440 cm and a width of 250 cm, with an overall height of 420 cm. The landing is designed with dimensions of 125 × 250 cm. The stair consists of 20 steps with a riser height of 20 cm and a tread width of 30 cm. As shown in Table 3, the reinforcement design uses Ø16–150 mm at the supports and Ø16–200 mm at midspan. This reinforcement configuration satisfies the flexural strength requirements and ensures user safety and comfort, which are particularly important for hospital buildings with high occupancy levels.

Table 3. Summary of stair reinforcement

Type	Position	Reinforcement
Stair	Support	Ø16 – 150
	Midspan	Ø16 – 200

3.8. Shear Wall Analysis

Shear walls were designed in the lift core and basement areas to serve as the primary lateral load-resisting elements. The analysis results indicate that both longitudinal and transverse reinforcements were provided to ensure adequate shear and flexural capacity. Special confinement reinforcement was applied at boundary elements to enhance ductility and seismic performance. This configuration improves the overall lateral resistance of the structure under earthquake loading. Tables 4 and 5 show the detailed reinforcement design of shear wall at lift core and basement.

Table 4. Summary of shear wall reinforcement at the lift core

Column Reinforcement	
Longitudinal	10 D22
Transversal	4 D13-100
Transversal)	4 D13-100
Main Reinforcement	
Longitudinal	2 D19-200
Transversal	2 D19-200
Confinement EBK (Transverse Direction)	3 D13-100
Confinement EBK (Longitudinal Direction)	3 D13-100

Table 5. Summary of shear wall reinforcement at the basement

Column Reinforcement	
Longitudinal	18 D22
Transversal	4 D13-100
Transversal)	4 D13-100
Main Reinforcement	
Longitudinal	2 D19-200
Transversal	2 D19-200
Confinement EBK (Transverse Direction)	3 D13-100
Confinement EBK (Longitudinal Direction)	3 D13-100

3.9. Foundation Analysis

The foundation system employs driven pile foundations with a pile diameter of 50 cm and an embedment depth of 22 m. The illustration of foundation analysis are shown in Figure 3. The selection of pile foundations is based on subsurface conditions and the magnitude of structural loads. This foundation configuration is expected to safely transfer both vertical and lateral loads to deeper soil layers, ensuring overall structural stability. Table 9 provides summary of whole analyses of foundation, describing Pile Cap type, number of spun piles.

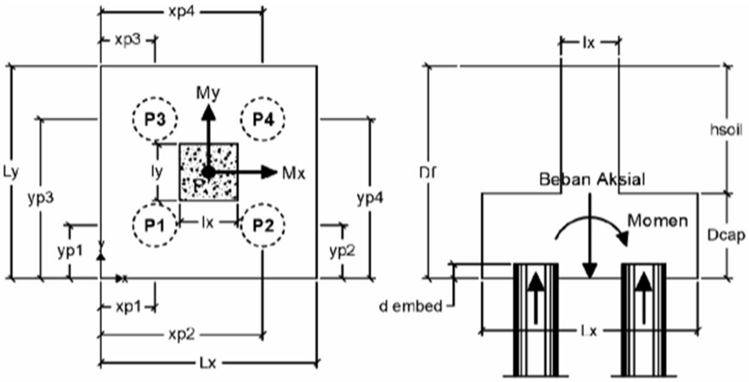

Figure 3. **Foundation analysis**

Table 9. Summary of Pile Foundation Calculation Results

Pile Cap Type	Column load (P)	Allowable Pile Capacity	Required Pile	Number of Pile
F1	7907,8871	2103,8	3,758858779	4
F1	6588,2299	2103,8	3,131585655	4
F1	6955,2212	2103,8	3,306027759	4
F1	6388,2299	2103,8	3,036519584	4
F1	6375,5557	2103,8	3,030495152	4
F2	4375,5557	2103,8	2,079834442	3
F2	5473,0779	2103,8	2,601520059	3
F2	5076,7074	2103,8	2,413113129	3
F2	4958,638	2103,8	2,356991159	3
F2	4958,4412	2103,8	2,356897614	3
F3	1235,45	2103,8	0,587246887	1
F3	2036,73	2103,8	0,968119593	1
F3	2014,43	2103,8	0,957519726	1
F3	1893,91	2103,8	0,900232912	1
F3	1867,1139	2103,8	0,887495912	1
F3	1346,5052	2103,8	0,640034794	1
F3	1386,5052	2103,8	0,659048008	1
F3	2066,8057	2103,8	0,982415486	1
F3	1772,23	2103,8	0,842394714	1
F3	1873,0889	2103,8	0,890336011	1
F3	1639,66	2103,8	0,779380169	1
F3	1595	2103,8	0,758151916	1
F3	1164,4	2103,8	0,553474665	1
F3	815,936	2103,8	0,387839148	1
F3	946,367	2103,8	0,449836962	1
F3	1872,75	2103,8	0,890174922	1
F3	1985,62	2103,8	0,943825459	1
F3	1308,45	2103,8	0,621946002	1
F3	1295,31	2103,8	0,615700162	1
F4	2777,9136	2103,8	1,320426657	2

Pile Cap Type	Column load (P)	Allowable Pile Capacity	Required Pile	Number of Pile
F4	2640,2715	2103,8	1,255001188	2
F4	2528,2251	2103,8	1,201742133	2
F4	3256,3339	2103,8	1,547834347	2
F4	2264,6528	2103,8	1,076458218	2
F4	3430,43	2103,8	1,630587508	2
F4	3057,15	2103,8	1,453156194	2
F4	2775,34	2103,8	1,319203346	2

3.10. Pile Cap Analysis

The pile cap design was carried out to ensure effective load transfer from the superstructure to the pile foundations. Four types of pile caps (F1–F4) were designed based on the magnitude of column loads and pile configuration requirements. As summarized in Table 10, the pile cap dimensions vary from 120 × 120 cm to 280 × 120 cm, with a uniform thickness of 80 cm. All pile caps are supported by driven piles with a diameter of 50 cm and an embedment depth of 22 m. The number of piles for each pile cap type ranges from one to four piles, depending on the applied structural loads. Larger pile caps with a greater number of piles are used for columns carrying higher axial loads, while smaller pile caps are applied to columns with lower load demands. This configuration ensures adequate bearing capacity, structural stability, and uniform load distribution to the pile foundation system, thereby satisfying strength and serviceability requirements.

Table 10. Summary of Pile Cap Calculation Results

Pile Cap Type	Dimension (cm)	Pile Cap Width (cm)	Pile Diameter (cm)	Pile depth (m)	Number of Pile
F1	225 x 225	80	50	22	4
F2	220 x 220	80	50	22	3
F3	120 x 120	80	50	22	1
F4	280 x 120	80	50	22	2

3.11. Discussion

The analysis results demonstrate that the structural configuration and material properties adopted for the five-storey hospital building provide an adequate basis for resisting gravity and lateral loads in accordance with applicable design standards. The use of reinforced concrete with a compressive strength of 30 MPa and reinforcing steel with yield strengths of 420 MPa and 280 MPa ensures sufficient stiffness and strength for a healthcare facility, which requires a higher level of structural reliability. The applied load combinations, including dead, live, wind, and seismic loads, reflect realistic operational and environmental conditions and form a consistent framework for evaluating structural performance.

The slab analysis indicates that both roof and floor slabs satisfy flexural capacity requirements with efficient reinforcement arrangements. The roof slab experiences relatively lower bending moments compared to the floor slab, which is expected due to the smaller live load contribution. Consequently, thinner slab thickness and lighter reinforcement spacing are sufficient for the roof slab. In contrast, the floor slab is subjected to higher bending moments, primarily due to larger imposed loads associated with hospital usage, necessitating increased slab thickness and denser reinforcement. This differentiation demonstrates that the slab designs appropriately reflect variations in load demand and functional requirements. The beam analysis further confirms that main beams carry significantly higher bending moments than secondary beams, resulting in larger cross-sectional dimensions and greater reinforcement requirements. This hierarchy in beam design ensures an effective load transfer mechanism from slabs to columns while maintaining structural efficiency. Similarly, the column analysis shows that larger columns with higher reinforcement ratios are provided at locations subjected to greater axial forces and bending moments. The variation between column types K1 and K2 reflects a rational design approach that matches member capacity with demand, enhancing overall structural stability.

Elements subjected to combined loading conditions, such as ramps and stairs, were designed with particular attention to safety and serviceability. The ramp analysis highlights the influence of inclination and traffic loads on bending moments, requiring conservative reinforcement in both principal directions. The stair design also meets flexural strength requirements while ensuring user safety and comfort, which are critical considerations for hospital buildings with high occupancy and frequent circulation. Lateral load resistance is primarily provided by shear walls located at the lift core and basement areas. The inclusion of longitudinal and transverse reinforcement, along with confinement reinforcement at boundary elements, enhances ductility and seismic performance. This configuration contributes significantly to the building's ability to withstand earthquake loading and reduces the demand on frame elements. The foundation system, consisting of driven piles with sufficient embedment depth, effectively transfers both vertical and lateral loads to deeper soil layers. The pile cap configurations were designed to distribute column loads uniformly to the piles, with larger pile caps and a greater number of piles used for columns carrying higher axial loads. This foundation strategy ensures adequate bearing capacity, minimizes differential settlement, and maintains overall structural stability. Overall, the results indicate that the structural elements, from superstructure to foundation, are designed in a consistent and integrated manner, with member dimensions and reinforcement levels appropriately responding to varying load demands. The combination of frame elements, shear walls, and pile foundations provides a balanced structural system that satisfies strength, serviceability, and seismic performance requirements, making it suitable for a hospital building where safety and functionality are paramount.

4. Conclusions

This study presented a comprehensive structural analysis and design evaluation of a five-storey reinforced concrete hospital building, including its roof and floor slabs, beams, columns, ramps, stairs, shear walls, and foundation system. A three-dimensional finite element model was developed to assess the structural response under gravity and seismic loads using material properties and load combinations in accordance with applicable design standards. The analysis results were used to determine appropriate member dimensions and reinforcement configurations for all major structural components.

The results indicate that the roof and floor slabs satisfy flexural capacity requirements with reinforcement layouts that reflect differences in load demand, where floor slabs require greater thickness and reinforcement due to higher live loads. Main beams and columns were designed with larger cross-sections and higher reinforcement ratios than secondary elements, ensuring adequate load transfer and overall structural stability. The shear wall system located at the lift core and basement plays a critical role in resisting lateral loads and enhancing seismic performance through adequate confinement and reinforcement detailing. The foundation system, consisting of driven piles and pile caps, effectively distributes structural loads to deeper soil layers and provides sufficient bearing capacity and stability.

Despite these findings, this study has several limitations. The analysis did not consider nonlinear material behavior, soil–structure interaction effects, or time-dependent factors such as creep and shrinkage. In addition, construction sequence, long-term serviceability performance, and detailed seismic performance evaluation under extreme earthquake scenarios were not explicitly investigated. Future research is recommended to incorporate nonlinear and performance-based seismic analysis, including pushover or time-history analysis, to better capture the structural behavior under strong ground motions. Further studies may also consider soil–structure interaction, construction stage analysis, and life-cycle performance assessment to improve the accuracy and applicability of structural design evaluations for hospital buildings and other essential facilities.

5. Declarations

5.1. Author Contributions

Conceptualization, Y.A.S. and K.U.; methodology, A.; software, Y.A.S.; validation, Y.A.S., K.U. and A.F.K.K.; formal analysis, Y.A.S.; investigation, A.; resources, A.; data curation, Y.A.S..; writing—original draft preparation, K.U.; writing—review and editing, A.F.K.K.; visualization, A.F.K.K..; supervision, A.; project administration, A. All authors have read and agreed to the published version of the manuscript.

5.2. Data Availability Statement

The data presented in this study are available on request from the corresponding author.

5.3. Funding

Funding information is not available.

5.4. Acknowledgements

The authors would like to express their sincere appreciation to all parties who contributed to the completion of this study. Special thanks are extended to the management of RSI NU Cakra Medika Hospital, Mayong, Jepara, for providing access to project data and technical information required for the analysis. The authors also acknowledge the support and facilities provided by the Department of Civil Engineering, Universitas Islam Nahdlatul Ulama Jepara, which greatly facilitated this research.

5.5. Conflicts of Interest

The authors declare no conflict of interest.

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