Transforming the West Sumatra Police Hall: Retrofitting Strategies for a Multifunctional Facility

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Abstract

The West Sumatra Regional Police Hall, initially designed as an open sports facility without a roof, is repurposed into a multifunctional center for sports activities, social events, and disaster emergency response. The existing structure, a portal frame of reinforced concrete columns and beams, requires strengthening due to budget constraints that prevent its demolition and reconstruction. This study aims to evaluate the structural performance of the building after retrofitting to accommodate additional loads, including a truss frame and roof coverings. The jacketing method is used for column retrofitting, involving an increase in cross-sectional dimensions and additional reinforcement to enhance the structure's strength and stiffness. Structural analysis shows that the original building lacks adequate capacity to withstand internal and external loads. Post-retrofitting, the analysis demonstrates significant improvements, including reduced shear forces and bending moments in columns and beams, minimized inter-level deflections, and compliance with column interaction diagrams. These enhancements ensure the building is structurally safe, particularly against seismic hazards, and capable of fulfilling its new functions. The findings highlight the effectiveness of the jacketing method for retrofitting and its potential application in similar structural repurposing projects.

Keywords: Retrofitting, Jacketing Column, Police Hall, Existing Building, Seismic Hazards

I. INTRODUCTION

The West Sumatra Regional Police Hall, a key sports facility within the police complex, was originally designed without a roof structure, making it inherently vulnerable to various structural issues. Despite its importance, the building now faces significant challenges regarding its structural integrity and seismic safety. The facility is set to be repurposed as a multifunctional center for sports, social events, and emergency response activities, requiring substantial modifications. These include the addition of truss structures and a roof covering to accommodate the new functions. However, demolishing the building and constructing a new one would incur substantial costs. Therefore, retrofitting the existing structure emerges as a more viable and cost-effective solution. This process involves a thorough assessment of the building's current state, followed by the implementation of necessary reinforcements to strengthen the structure and address its weaknesses. The retrofitting will not only ensure the building's stability and seismic resilience but also guarantee the safety and well-being of its future occupants. By upgrading the structure, the facility will be able to effectively serve its new purpose while avoiding the high costs and disruptions associated with full demolition and reconstruction.

Previous studies have demonstrated that column jacketing significantly enhances the structural strength and performance of buildings subjected to increased loads or seismic events. Many studies focus on retrofitting buildings that have sustained damage due to seismic activity or are designed to increase load-bearing capacity under normal operational conditions. However, the current research expands the scope by addressing proactive retrofitting, specifically in the context of repurposing an existing open sports facility into a multi-functional activity center, which demands additional load from roof structures and trusses. While prior studies primarily emphasize post-disaster retrofitting, such as the concrete jacketing of buildings like the Korem 012/TU Mess Building in Meulaboh, Aceh, this study aims to proactively enhance structural safety to mitigate seismic risks while accommodating functional changes [1][2][3][4][5]. For example, in the case of the Andalas University Faculty of Nursing building, the need for column and beam structural reinforcement was identified due to low concrete quality and insufficient load-bearing capacity, which was addressed through redesign and strengthening [6][7][8].

Further research has evaluated column jacketing in various buildings, showing notable improvements in load-bearing capacity. The Baiturrahman Mosque heritage area revitalization project in Semarang, for example, revealed a significant increase in both compressive strength and moment capacity of columns after jacketing, with K1 columns experiencing a 773% increase in compressive strength and K3 columns exhibiting a 115% increase [6]. Similarly, in the BPKP building, column jacketing was effective in reducing internal forces and minimizing displacements under loads [7]. Structural retrofitting using the jacketing method has also been shown to restore damaged columns, as evidenced by the restoration of the Andalas Grand Mosque in Padang and the Grand Mosque in Bima, where jacketing increased structural capacity and ensured the safety of the buildings [8][9]. These findings support the effectiveness of column jacketing as a retrofit solution for both strengthening and restoring damaged structures. The Indralaya Shop House study extended the analysis by assessing internal forces, displacements, and column interaction diagrams, offering a comprehensive evaluation of structural behavior post-retrofit [10].

Additionally, economic factors have become important considerations in retrofitting strategies. Concrete jacketing has been shown to be both cost-effective and efficient in improving structural stiffness, although its implementation can be time-consuming and challenging due to construction limitations [11]. A comparative study of different reinforcement methods, such as steel jacketing and carbon fiber reinforced polymers (CFRP), highlighted the cost-effectiveness and performance of steel jacketing, with the CFRP method demonstrating a higher initial cost but faster execution and lower operational revenue losses [12]. Moreover, the addition of lateral reinforcement and variations in concrete jacket strength have been found to significantly enhance axial capacity and ductility in reinforced concrete columns [13][14][15]. This study also explores alternative materials, such as Ultra-High-Performance Fiber-Reinforced Concrete (UHPFRC) and CFRP, which have been used in strengthening reinforced concrete structures to improve their capacity under seismic conditions [16][17]. Furthermore, the application of CFRP for strengthening connections between beams and columns has shown to increase load-bearing capacity by up to 25%, while glass fiber reinforced polymer (GFRP) retrofitting improved lateral capacity and ductility of columns subjected to seismic loads [18][19][20]. Lastly, the use of ferro-cement wrapping for column retrofitting demonstrated notable improvements in axial load capacity, further expanding the range of viable retrofitting techniques [21].

This study aims to evaluate and implement structural strengthening measures for the West Sumatra Regional Police Hall, which is being repurposed from an open sports facility without a roof into a multifunctional activity center with additional structural loads from truss and roof coverings. The building's new functions include sports activities, hosting social events, and serving as a disaster emergency response center. Budget constraints necessitated the structural retrofitting approach, with the research focusing on assessing the structural performance of the existing building and determining its capacity to accommodate the additional structural loads from truss and roof coverings. The study investigates the effectiveness of the jacketing method, a retrofitting technique involving cross-sectional enlargement and reinforcement addition, to enhance the building's strength, stiffness, and stability. Key structural parameters, such as internal forces, inter-story displacements, and column interaction diagrams, are analyzed to evaluate the impact of retrofitting on overall performance. The ultimate goal is to ensure that the building meets safety standards, resists seismic hazards, and is structurally adequate for its intended multifunctional use.

II. Method

This study was conducted to evaluate and strengthen the structure of the West Sumatra Police Headquarters Hall. Initially, the building was designed as an open-air sports facility without a roof. However, it was later transformed into a multifunctional activity center for sports, social events, and disaster emergency responses. The research approach focused on retrofitting methods as an alternative to address budget constraints compared to the costly process of demolition and reconstruction. Among the retrofitting techniques, the jacketing method was chosen to enhance the strength of concrete columns. This was necessary to enable the columns to bear additional loads imposed by the installation of a roof frame and covering. The research design comprised an initial structural analysis of the existing building, followed by precise load calculations. Simulations were conducted to predict the performance of the strengthened concrete columns after the application of the jacketing technique. The process concluded with a comprehensive evaluation comparing the structural performance of the building before and after reinforcement. This evaluation provided valuable insights into the effectiveness of the retrofitting measures in meeting the building's new functional requirements.

Data collection in this study was carried out through direct preliminary field surveys. These surveys aimed to gather comprehensive information about the existing building's structural condition. Key data included the dimensions of structural elements such as columns, beams, and other load-bearing components. Additionally, information was gathered regarding the internal and external loads acting on the building. The process involved a detailed review of structural design documents to understand the initial framework and specifications. Field observations were also conducted to evaluate the physical condition of the building in real-time. Advanced engineering software was utilized to simulate the structural performance under various conditions. Parameters such as shear forces, bending moments, inter-story deflection, and column interaction diagrams were analyzed. These parameters helped identify the building's structural strength after retrofitting and provided a basis for evaluating the applied reinforcement techniques.

The analysis of the collected data was performed in multiple stages to ensure the reinforced structure met safety and stability standards. The first stage involved evaluating the existing structural capacity to identify areas of weakness. This provided a baseline for determining the effectiveness of the retrofitting process. Subsequently, the application of the jacketing method was analyzed to assess its impact on strengthening the concrete columns. Key focus areas included changes in internal forces within the columns, reductions in inter-story deflection, and enhancements in the structure's ability to bear additional loads. Interaction diagrams for the columns were utilized to verify that all internal forces remained within safe operational limits after the reinforcement. This analysis highlighted the improvements in earthquake resistance and confirmed the building's readiness to fulfill its new multifunctional purposes.

III. RESULTS AND DISCUSSION

A. Evaluation of Existing Structure

The existing structural system of the West Sumatra Police Hall consists of a combination of reinforced concrete columns and beams, supported by masonry walls. This configuration forms the primary framework of the building, providing the structural integrity required for its functional purposes. As depicted in Figure 1, the building's structural design incorporates the interplay of these elements to distribute loads and maintain stability under various conditions, including operational and potential seismic forces. The reinforced concrete columns and beams serve as the critical load-bearing elements, while the masonry walls, though not primary load-bearing components, contribute to the building's overall structural strength by providing lateral stability and enclosure.

(a) (b) (c)

Figure 1 (a), (b) Building Condition and (c) Measure Column Dimensions

The structural assessment of the West Sumatra Police Hall includes detailed inspection and testing to evaluate the condition and performance of the materials used. Figure 1(a) and (b) illustrate the current condition of the building, showcasing any visible signs of deterioration or structural issues that may affect the overall safety and functionality of the structure. These visual assessments are crucial for identifying potential areas of concern, such as cracks, settlements, or signs of material degradation, which could compromise the building's ability to withstand imposed loads or seismic forces.

To further assess the quality of the concrete used in the columns and beams, a hammer test survey was conducted. This non-destructive testing method provides valuable insights into the compressive strength of the concrete without causing any damage to the structure. The results of the hammer test, as shown in Figure 1(c), indicate that the average compressive strength of the concrete in the West Sumatra Police Hall is 17.29 MPa. This value is a critical factor in determining the structural performance of the building, as it directly influences the load-bearing capacity and the potential for future deterioration under cyclic or seismic loads. The compressive strength of the concrete is an essential parameter for evaluating the adequacy of the current structural design, and these findings may inform decisions regarding potential retrofitting or strengthening interventions to ensure the long-term safety and functionality of the building.

1. Structural System

The hall's structural design consists of a reinforced concrete framework, which has been classified under risk category III due to its primary function as a meeting facility. This classification reflects the building's importance in terms of safety and functionality, particularly in areas that may experience seismic activity. The choice of a reinforced concrete framework aligns with the need for a durable, robust structure that can withstand dynamic forces, including those generated by seismic events. Given the seismic design category D, which indicates a moderate to high level of seismic risk, the adopted structural system for analysis is the special moment-resisting frame (SMRF). This system is specifically designed to provide enhanced resistance to lateral forces caused by earthquakes. The special moment-resisting frame ensures the building's ability to maintain structural integrity during seismic events, offering both strength and flexibility to resist the demands of seismic forces while minimizing potential damage.

2. Building Structure Data Existing

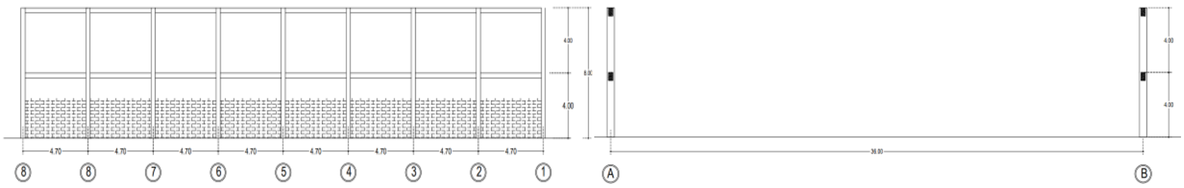
The structural data provided in Table 1 pertains to the West Sumatra Police Hall, a reinforced concrete building currently under evaluation. The building is characterized by its 8-meter height and reinforced concrete framework, which includes columns and beams with specific dimensions and concrete quality. The columns have a cross-sectional dimension of 30 cm by 30 cm, while the beams measure 25 cm by 30 cm. The existing concrete quality, denoted as fc′=17.29f_c' = 17.29 MPa, reflects the compressive strength of the concrete, which plays a critical role in determining the overall structural capacity. This building serves as a case study for evaluating the performance and potential retrofitting methods aimed at enhancing its load-bearing capacity, particularly in light of seismic and operational demands. The following sections analyze the structural integrity of this building, taking into account its dimensions, material properties, and height, as well as proposing necessary strengthening methods based on the existing conditions.

Table 1 Building Data Existing

Information	Description
Name of Building	West Sumatra Police Hall
Structure Type	Concrete Reinforced
Existing Concrete Quality	fc’=17,29 MPa
Building Height	8 Meter
Column Dimension	(30x30) cm
Beam Dimension	(25x30) cm

The West Sumatra Police Hall is a concrete-reinforced structure with a height of 8 meters. The existing concrete quality is rated at a compressive strength of fc’ = 17.29 MPa, indicating moderate strength, which is an important factor in assessing the building’s ability to withstand applied loads. The column dimensions are (30x30) cm, providing a relatively standard cross-sectional area for load-bearing, while the beam dimensions are (25x30) cm, which are slightly smaller in comparison, indicating that the beams are designed to carry distributed loads across spans between columns. The structural configuration and material properties suggest a need for careful evaluation of the building's capacity to resist seismic forces and additional loads, especially considering the relatively low concrete strength, which may limit the building's overall durability and stability under extreme conditions.

Furthermore, the structural analysis of the West Sumatra Police Hall was conducted using advanced 3D structural modeling with the ETABS v9.7.1 software. This software provides an efficient and accurate method for analyzing complex structural behavior by simulating various loads and forces on the building. The 3D model allows for a comprehensive understanding of the structural system’s performance under different conditions, including dead loads, live loads, and seismic forces. Figures 2 and 3 present the visual representation of the hall, with Figure 2 showing a perspective view of the building's overall structure and Figure 3 providing a detailed floor plan. These figures help to illustrate the layout of the hall and the arrangement of structural elements, such as columns, beams, and slabs, which are essential in determining the building's capacity and stability. The use of ETABS ensures that the analysis is precise, aiding in the identification of potential weaknesses and ensuring that the hall meets safety and design standards.



(a) (b

Figure 2 (a) The Front and (b) Side Views of the Hal

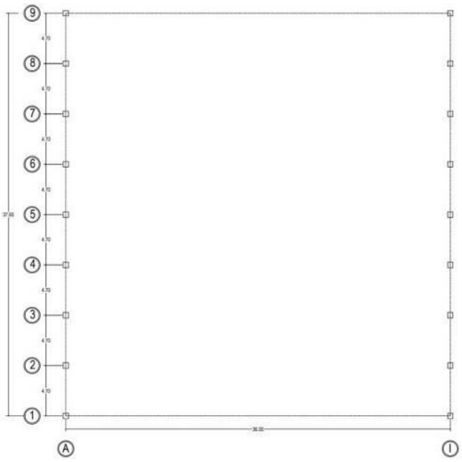


Figure 3 The Plan of the Hall

The columns and beams in this building are designed and modeled as a portal frame structure, which is a common structural configuration used to resist both vertical and lateral loads. In this research, the primary focus is on strengthening the column structures, particularly those subjected to additional loads from the steel truss structures. The steel trusses impose significant forces on the columns, especially in terms of vertical loads and potential lateral forces. Therefore, the study aims to evaluate and enhance the column capacity to safely bear these increased loads while maintaining the overall stability of the building. Strengthening the columns is essential to ensure that they can effectively transfer the applied forces without compromising the structural integrity of the portal frame system. The research will explore various reinforcement techniques to improve the performance of the columns under these new loading conditions, ensuring that the building can meet safety standards and perform optimally under both normal and extreme load scenarios.

3. Spectrum Response Analysis

The response spectrum analysis is a structural dynamic analysis method applied to the seismic response spectra of a design. It determines the spectrum response to a design earthquake through the superposition of responses for each vibration mode. This method is widely used due to its simplified approach for calculating the design strength of structures and evaluating structural systems subjected to seismic loads. In this study, the response spectrum design for earthquake loads was developed in accordance with SNI 1726:2019. Based on soil test results, the building site is classified as medium soil. Figure 4 illustrates the response spectrum design for the specific soil conditions in Padang.

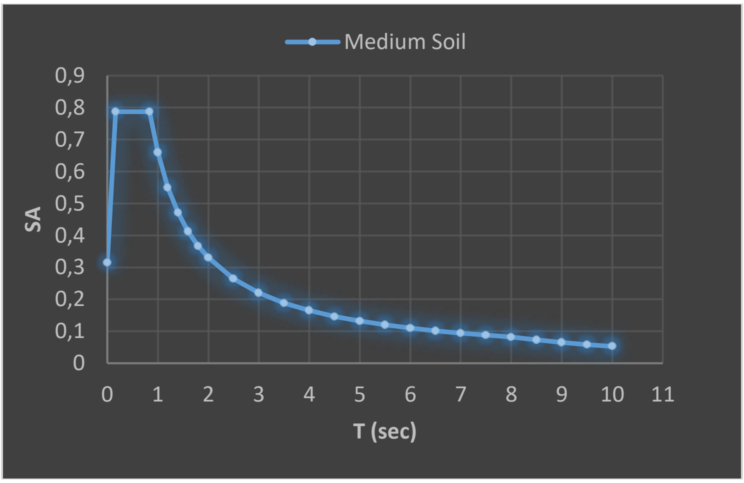


Figure 4 Spectrum Response Design for Earthquake Load in Padang based on SNI 1726:2019

As presented in table 2, the analysis of structural column strength at a height of 0–4 meters reveals that the columns lack sufficient capacity to withstand the applied load. The ultimate moment in this section is 143.33 kN·m, whereas the column's capacity is only 77.97 kN·m. Similarly, for the column section between 4 and 8 meters, the ultimate moment is 85.42 kN·m, while the column's capacity is 77.96 kN·m, indicating insufficient strength. Regarding the beam elements at an elevation of 4 meters, as shown in Table 3, the largest moment occurs at the support area, measured at -35.98 kN·m, which exceeds the beam's capacity of 33.41 kN·m. This suggests that the beam is unable to handle the applied load. However, for the beam element at an elevation of 8 meters, the moment is -16.63 kN·m, which remains within the beam's strength capacity of 33.41 kN·m, indicating a safe condition.

Table 2 The Strength Capacity of a Column

Hight (m)	Dimension (mm)	ΦVn (kN)	Vu (kN)	Momen (kN.m)	Mu (kN.m)	Description
0-4	30 x 30	109,91	35,57	77,96	-143,33	Not Oke
4-8	30 x 30	109,91	45,50	77,96	-85,42	Not Oke

Table 2 presents the strength capacity of a column with varying heights and dimensions, as indicated by the shear force (ΦVn), maximum shear force (Vu), moment (Momen), and maximum moment (Mu). For the section from 0 to 4 meters, the column dimension is 30 x 30 mm, with a shear force capacity of 109.91 kN, a maximum shear force of 35.57 kN, a moment capacity of 77.96 kN·m, and a maximum moment of -143.33 kN·m. For the section from 4 to 8 meters, the same column dimension results in a shear force capacity of 109.91 kN, a maximum shear force of 45.50 kN, a moment capacity of 77.96 kN·m, and a maximum moment of -85.42 kN·m. Both sections are marked as "Not Oke," indicating that these columns do not meet the required performance criteria.

Table 3 The Strength Capacity of a Beam

Elv.(m)	Dimension (mm)	Support		Field		Support		Field		Description
		ΦVn (kN)	Vu (kN)	ΦVn (kN)	Vu (kN)	Momen (kN.m)	Mu (kN.m)	Momen (kN.m)	Mu (kN.m)	
4	25 x 30	41,47	-12,02	31,90	-8,99	33,41	-35,98	33,41	13,31	Not Oke
8	25 x 30	41,47	-9,96	31,90	-8,46	33,41	-16,63	33,41	8,08	Oke

The data in table 3 presents the structural performance of two different elements at two elevation levels (Elv. 4m and Elv. 8m) with dimensions of 25 x 30 mm. The first set of values at 4 meters shows a shear capacity (ΦVn) of 41.47 kN for the support and -12.02 kN for the field, with a maximum shear force (Vu) of -8.99 kN for the field. The moment capacity (M) at this elevation is 33.41 kN·m for both the support and field, while the moment at the support is -35.98 kN·m and at the field is 13.31 kN·m, indicating that the structural element does not meet the required performance (Not Oke). In contrast, the data at 8 meters shows a shear capacity (ΦVn) of 41.47 kN for the support and -9.96 kN for the field, with a maximum shear force (Vu) of -8.46 kN for the field. The moment capacity (M) remains 33.41 kN·m for both support and field, with the moment at the support being -16.63 kN·m and at the field 8.08 kN·m, indicating the element meets the required performance (Oke).

4. Cross-sectional Capacity of the Structure

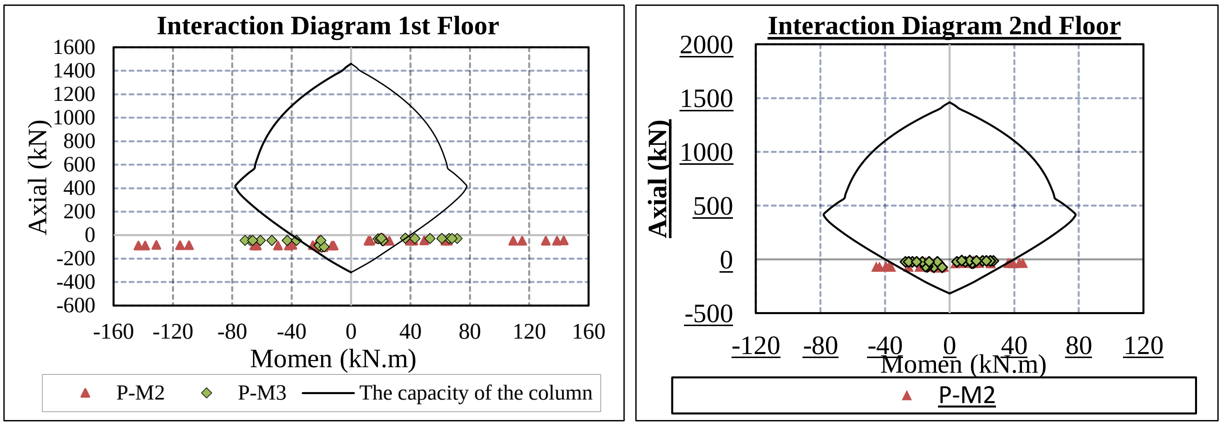


Figure 5 (a) First Floor and (b) Second Floor Existing Column P-M Interaction Diagram

5. Displacements

The displacement of the building structure is determined from the largest displacement value on each floor. Based on Figure 6, the graph illustrates the relationship between building height and floor displacement, revealing that the inelastic drift in both the X and Y directions exceeds the allowable drift limit. This indicates that the deviation surpasses the required maximum limit, which can be attributed to the low structural stiffness of the building. To address this issue, it is necessary to increase the column dimensions to enhance the structural stiffness.

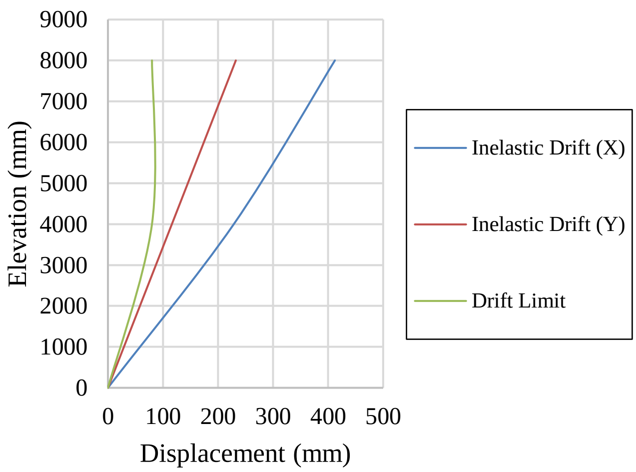


Figure 6 Story Drift Existing Column

Furthermore, data presented in the following table 4 reveals a concerning discrepancy when evaluating the safety of the structure based on floor displacement values at elevations of 4000 mm and 8000 mm. Specifically, the largest displacement values recorded in the x-direction were 412.28 mm at 4000 mm and 228.67 mm at 8000 mm, both of which exceed the specified displacement limit of 80 mm. These values significantly surpass the acceptable displacement threshold, indicating that the structural integrity is compromised at these elevations. Given that such displacements are well above the design limit, it can be concluded that the structure fails to meet the required safety criteria, raising concerns about its stability under the observed conditions.

Table 4 The Inter-Floor Displacement on Existing Columns

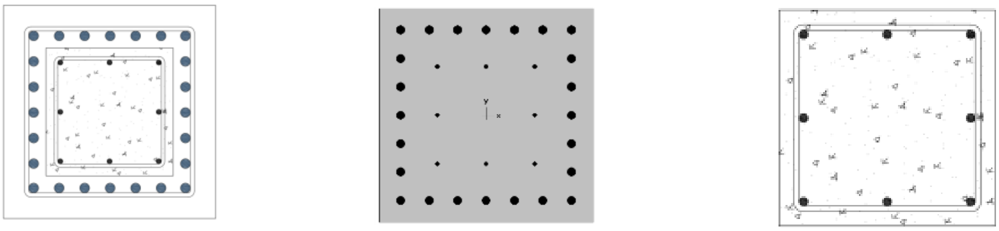
Elevation (mm)	Displacement		Elastic Drift		h (mm)	Inelastic Drift		Drift Limit	Check
	δeX (mm)	δeY (mm)	δeX (mm)	δeY (mm)		ΔX (mm)	ΔY (mm)	(mm)	
8000	145,67	79,20	93,70	52,800	4000	412,28	232,32	80,00	Not Ok
4000	51,97	26,40	51,97	26,400	4000	228,67	116,16	80,00	Not Ok
0	0,00	0,00	0,00	0,00	4000	0,00	0,00	0,00	

6. Retrofitting Column Using Jacketing Method

Column reinforcement is carried out using the Concrete Jacketing Method on all columns reinforced concrete. The position of the Concrete Jacket Column is shown in Figure 7(b).Column reinforcement using the jacketing method is carried out by enlarging the dimensions and adding reinforcing steel to the column with the following assumptions. Retrofitting column dimensions are 600 x 600 (mm). The column quality to be achieved is fc'=20,75 MPa, In order to reach a concrete quality of fc'=20,75 MPa, then the concrete quality for column retrofitting must be achieved at least fc'= 21,90 MPa. Calculation of concrete quality for retrofitting columns is as follows, Column quality to be achieved (A)= 22,69 MPa, concrete quality existing (B) = 11,24 MPa, Planed column area (C)= 600x600= 360.000 mm², existing column area (D) =300x300= 90.000 mm², Jacketing area (E) = 270.000 mm².Quality of concrete jacketing:

$$(D \times B) + (E \times X) = C \times A$$
$$(90{,}000 \times 17.29) + 270{,}000 \times (X) = 360{,}000 \times 20{,}75$$
$$X = 21{,}90 \text{ MPa}$$

The amount of reinforcement added is 24D22 mm, with steel quality of fy=240 MPa. Fig. 8 (c) can be seen modeling from the definition of the jacketing column in the SPColumn software. Figure 8 (a) (b) shows a comparison of the column cross-section between the existing column and the column jacket.



(a) Existing Column **(b) Concrete Jacketing Column** **(c) Model jacketing column**

Figure 7 Concrete Jacketing Column Reinforcement Modeling

(a) **(c)** **(b)**

Figure 8 (a), (b) and (c) Documentation of the Reinforcement Process Using the Column Jacketing Method

The work process begins with the column, as shown in Figure 8(a). This involves cleaning the existing column, adding reinforcement, constructing formwork, and completing the process with concrete casting. After all columns have been reinforced, the cutting and assembling of the truss structure are carried out simultaneously in the factory using steel pipe materials, as depicted in Figure 8(b). Finally, the truss structure is installed on-site with the assistance of a crane, as illustrated in Figure 8 (c).

7. The Analysis of the Structures Design

The structural modeling and analysis of the hall building were carried out using advanced 3D structural modeling techniques with ETABS 2016 software, a widely recognized tool for evaluating and simulating the behavior of buildings under various loads. This modeling process enabled a detailed representation of the building's geometry, load distribution, and structural elements, allowing for accurate assessments of its performance. Figures 9 and 10 present the building’s floor plans and structural views, which provide a comprehensive visualization of the modeled structure. These figures offer a clear depiction of the spatial arrangement, as well as the layout and configuration of key structural components such as columns, beams, and load-bearing walls. The use of such visual tools not only enhances the clarity of the analysis but also supports a thorough evaluation of the building’s overall stability and structural integrity. Through this approach, the structural behavior of the hall building can be effectively analyzed, ensuring that the design meets safety and performance criteria.

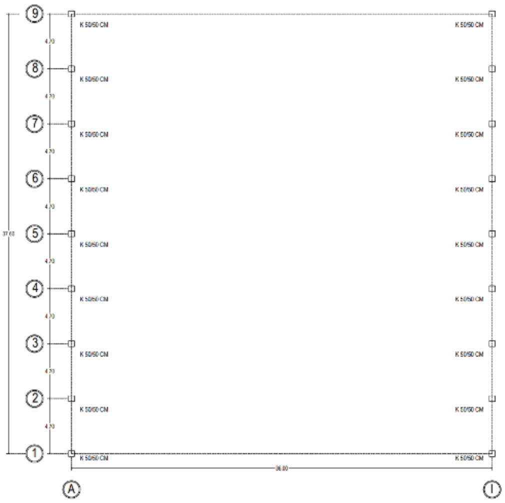


Figure 9 The Plan of the Hall

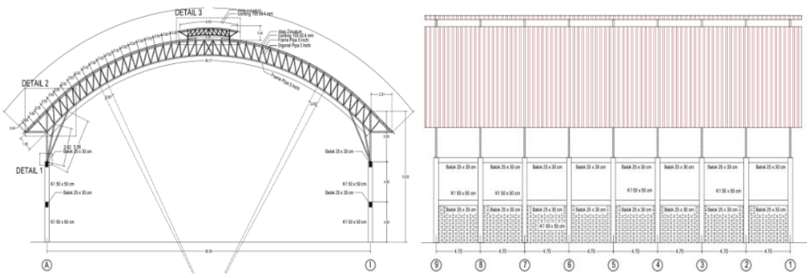


Figure 10 (a) The Front Side and (b) Side Views of the Hall

The effectiveness of enlarging and reinforcing column dimensions is demonstrated by a significant improvement in the load-bearing capacity of both the columns and beams, enhancing the overall structural integrity. By increasing the cross-sectional area and adding reinforcement, the columns show improved resistance to shear forces and bending moments, which are essential for maintaining stability under both static and dynamic loads. This modification not only increases strength but also optimizes the distribution of internal forces, ensuring more efficient performance under various stresses. As shown in Tables 5 and 6, the structure is safely capable of supporting the applied loads, with the analysis confirming its adequacy in terms of safety and performance.

Table 5 The Strength Capacity of a Column

Hight (m)	Dimension (mm)	ΦVn (kN)	Vu (kN)	Momen (kN.m)	Mu (kN.m)	Description
0-4	60 x 60	296,15	44,58	912,23	-332,63	Oke
4-8	60 x 60	296,15	40,64	683,91	-156,39	Oke

Table 6 The Strength Capacity of a Beam

Higth (m)	Dimension (mm)	Support		Field		Support		Field		Check
		ΦVn (kN)	Vu (kN)	ΦVn (kN)	Vu (kN)	Momen (kN.m)	Mu (kN.m)	Momen (kN.m)	Mu (kN.m)	
4	25 x 30	41,47	-8,08	31,90	-2,65	33,41	-10,23	33,41	7,26	Oke
8	25 x 30	41,47	-8,60	31,90	-2,45	33,41	-11,34	33,41	7,22	Oke

Table 7 provides the displacement measurements for retrofitted columns, revealing values of 36.08 mm at an elevation of 4000 mm and 77.44 mm at an elevation of 8000 mm. These displacements are both well within the maximum allowable limit of 80.00 mm, which serves as the threshold for acceptable structural behavior under load. Given that the observed displacements are significantly below this limit, it can be concluded that the retrofitted columns are structurally sound and capable of withstanding the applied loads without posing a risk of failure. This suggests that the retrofitting measures have successfully enhanced the columns' performance, ensuring they remain within the required safety margins for displacement.

Table 7 The Displacement Between Floors with Retrofitting Columns

Elevation (mm)	Displacement		Elastic Drift		h (mm)	Inelastic Drift		Drift Limit (mm)	Check
	δeX (mm)	δeY (mm)	δeX (mm)	δeY (mm)		ΔX (mm)	ΔY (mm)		
8000	25,80	6,73	17,60	4,19	4000	77,44	18,43	80,00	OK
4000	8,20	2,54	8,20	2,54	4000	36,08	11,17	80,00	OK
0	0,00	0,00	0,00	0,00	0	0,00	0,00	0,00	

The results demonstrate the impact of reinforcement on the structural columns in controlling the inter-floor displacement of the building. The displacement values, derived from the largest displacement on each floor, are analyzed. Based on Figure 11, the graph illustrates the relationship between building height and floor displacement, showing that inelastic drift in both the X and Y directions remains within the allowable drift limits. This indicates that the observed deviations comply with the required standards, confirming that the column dimensions meet the necessary stiffness requirements.

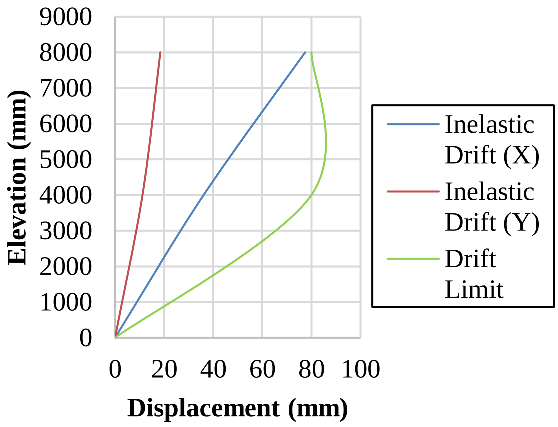
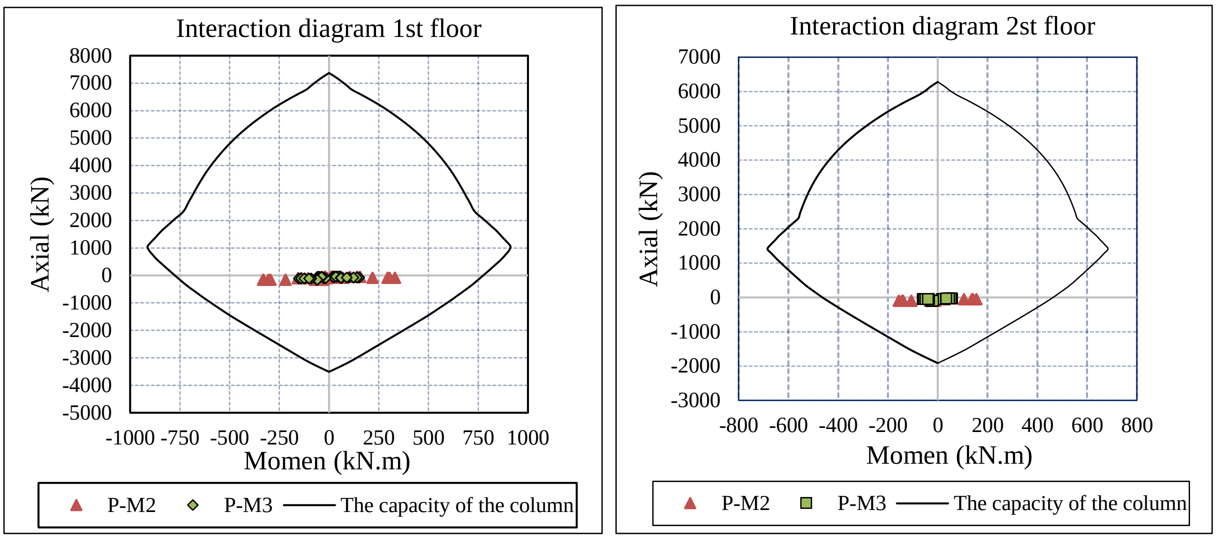


Figure 11 Story Drift Retrofitted Column

Based on the column interaction diagrams presented in Figures 12(a) and 12(b), it can be concluded that the columns exhibit sufficient strength to resist the forces acting upon them, both on the first and second floors. The analysis of the relationship between axial forces and moments acting on the columns indicates that all these forces are contained within the boundaries of the column interaction diagram. This demonstrates that the column design effectively accommodates the combined effects of axial and moment loads, ensuring structural stability and compliance with safety criteria.



(a) **(b)**

Figure 12. First Floor and Second Floor Retrofitted Column Design P-M Interaction Diagram

The column interaction diagrams provided in Figures 12(a) and 12(b) illustrate that the retrofitted columns at both the first and second floors exhibit sufficient strength to resist the forces acting upon them. These diagrams depict the relationship between the axial forces and bending moments, and the analysis reveals that all these forces are well within the boundaries defined by the column interaction diagram. Specifically, for both floors, the axial forces and moments are positioned in a way that falls inside the safe zone of the interaction curve, which indicates that the columns are designed to effectively handle the combined effects of axial and moment loads. This further affirms that the columns are structurally capable of maintaining their stability under the applied loads. As the forces do not exceed the limits defined by the interaction diagrams, the design demonstrates that the columns not only satisfy the requirements for structural integrity but also comply with the necessary safety standards. Thus, the retrofitting measures are proven to be effective in ensuring the columns' ability to resist these loads without risk of failure, ensuring both the durability and the safety of the structure.

IV. CONCLUSIONS

Based on the analysis of the existing structure, considering internal parameters such as internal forces acting on column and beam elements, inter-story displacement, and the interaction diagrams within the existing column elements, it can be concluded that the structure lacks sufficient capacity to withstand the additional loads from the frame structure. The strength of the first and second-floor columns was found to not meet the moment capacity requirements, with a resistance moment of 77.96 kN·m being less than the ultimate moment of 143.33 kN·m. Similarly, the strength of the beam at a 4-meter elevation had a moment capacity of 33.41 kN·m, which was less than the ultimate moment of 35.98 kN·m. Additionally, the column interaction diagrams indicated overall failure in resisting axial forces and moments. Finally, in terms of structural rigidity, the observed displacements also failed to meet the requirements, with the largest displacements in the x-direction being 412.28 mm and 228.67 mm, exceeding the allowable displacement limit of 80 mm.

To address these issues, column elements were reinforced using the jacketing method, which involved increasing the dimensions and adding both main and shear reinforcement. The reinforcement significantly improved the structural rigidity, resulting in column and beam capacities exceeding the internal forces acting on them. After retrofiting, the strength of the first and second-floor columns met the moment capacity requirements, with a resistance moment of 912.23 kN·m exceeding the ultimate moment of 332.63 kN·m for the first floor, and 683.91 kN·m exceeding the ultimate moment of 156.39 kN·m for the second floor. For the beam at a 4-meter elevation, the moment capacity was 33.41 kN·m, exceeding the ultimate moment of 7.26 kN·m. Furthermore, the column interaction diagrams demonstrated an overall improvement in column capacity to resist axial forces and moments. Lastly, the structural rigidity also met the requirements, with the largest displacements in the x-direction being 77.44 mm and 36.08 mm, which were within the allowable displacement limit of 80 mm.

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