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SEISMIC ASSESSMENT AND RETROFITTING OF THE WEST SUMATRA BPBD OFFICE BUILDING USING SHEAR WALLS

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ABSTRACT: The structural reliability of public buildings in seismic-prone areas is essential to ensure safety and functionality. Accordingly, the BPBD office building in Padang, West Sumatra, Indonesia, was evaluated due to observed deficiencies, including cracking, material degradation, and inadequate lateral resistance under Indonesian building standards. Structural modeling and analysis using ETABS showed that the existing structure does not meet inter-story drift requirements, with excessive drift at the second floor. In addition, several columns experienced moment and axial failure, and several beams experienced shear failure, reducing seismic performance. To address these deficiencies, a global retrofitting strategy was implemented by adding RC shear walls along the weak axis. Re-analysis of the retrofitted model demonstrated significant improvements: inter-story drift values complied with code requirements, column internal forces decreased by up to 95% moment, 93% shear, and 30% axial, while beam internal forces were reduced by 81% in moment and 63% in shear. Furthermore, floor slab analysis revealed inadequate flexural capacity under seismic loads. Strengthening with Fiber Reinforced Polymer (FRP) sheets successfully increased the slab moment capacity from 0.89 t.m to 2.62 t.m, exceeding the external moment requirement of 2.51 t.m. These results confirm that a combined retrofitting strategy using shear walls to enhance global stiffness and FRP to reinforce slab flexural strength provides an effective solution to improve seismic resilience and ensure the building's safety as a disaster management facility. Fragility curve analysis further indicates that, after retrofitting, the probability of exceeding all damage states decreases significantly, confirming a substantial reduction in seismic damage risk.

Keywords: Structural Assessment, Retrofitting, Shear Wall, Earthquake, RC structure

1. INTRODUCTION

The structural durability of buildings is a crucial factor in ensuring the safety of occupants and the sustainability of building functions, especially in areas with high seismic rates such as West Sumatra [1,2]. The building, which is located behind the West Sumatra Governor's Office, is one of the strategic infrastructures located in Padang City, Indonesia, and it is planned to function as an office of the Regional Disaster Management Agency (BPBD).

The results of the visual review show that the existing condition of the building has experienced various damages, including cracks in the floor slabs, damage to the beams, and indications of concrete segregation that have the potential to reduce the overall performance of the structure. This confirms that even though it is classified as a new building, its structural performance requires a thorough technical evaluation.

On the other hand, changes in earthquake design standards in Indonesia, especially the implementation of SNI 1726:2019 on earthquake resistance [3], SNI 2847:2019 on reinforced concrete structures [4], and SNI 1727:2020 on minimum load of buildings [5], require a re-evaluation of buildings designed using the old standards. This condition is a serious challenge considering that a number of public buildings, including the BPBD office Building, have the potential to not meet the latest requirements.

Previous studies have shown that global retrofitting methods such as shear wall installation are an effective solution in increasing the capacity of structures against lateral forces, reducing inter-story drift, and increasing the rigidity of structural systems [6-8]. The application of shear walls is also able to transform the structural system into a dual system, making it more reliable in withstanding earthquake loads [9-10].

2. RESEARCH SIGNIFICANCE

This study highlights the importance of retrofitting critical public buildings in seismic-prone regions. By assessing the BPBD office's structural deficiencies and implementing a combined retrofitting strategy with reinforced concrete shear walls and FRP sheets, the research demonstrates effective methods to enhance seismic resilience. The findings provide practical insights into improving global stiffness, reducing inter-story drift, and increasing slab flexural capacity, ensuring both safety and functionality. Beyond technical analysis, the study also emphasizes the need to address implementation challenges, including construction phasing and occupancy management, making it relevant for disaster management facilities in Indonesia and similar contexts.

3. METHODOLOGY

3.1 Building Data

The existing condition of the BPBD building is shown in Fig. 1.

Fig.1 Existing conditions of the BPBD building

The technical specifications of the structure for the analysis of this building are as follows:

Building Location : Padang City, West Sumatra Province
Structural System : Reinforced Concrete Portal
Floor Slab Width : 12 cm
Concrete Grade : 260 kg/m^2
Reinforce Grade (Fy): 240 MPa
Soil Condition : Medium Soil (SD)

Details of the structure of columns and beams, including rebar, are shown in Tables 1 and 2.

Table 1. Column details

No	Code	Dimensions (mm)		Lo (mm)	Shear Rebar	
		Diameter	Height		Support	Midspan
1	K1D60	600	4600	692	3D-10-100	2D10-150
2	K2D60	600	4600	692	3D-10-100	2D10-150
3	K3D60	600	3600	532	3D-10-133	2D10-150
4	K4D60	600	3600	532	3D-10-133	2D10-150
5	K5D60	600	3600	532	3D-10-133	2D10-150

Table 2. Beam details

No	Code	Dimension		Rebar		Shear Rebar	
		Width	Depth	Tensile	Compr.	Support	Midspan
1	S1	300	500	7 D 25	4 D 25	1Φ10 - 100	Φ10 - 150
2	S2	300	500	8 D 25	4 D 25	1Φ10 - 100	Φ10 - 150
3	B1	300	500	7 D 25	4 D 25	1Φ10 - 100	Φ10 - 200
4	B2	300	500	8 D 25	4 D 25	1Φ10 - 100	Φ10 - 200
5	B3	300	500	9 D 25	5 D 25	1Φ10 - 100	Φ10 - 260
6	BA1	250	450	3 D 19	2 D 19	1Φ10 - 100	Φ10 - 220
7	BA2	200	300	3 D 16	2 D 16	1Φ10 - 100	Φ10 - 260
8	BK1	300	500	4 D 25	2 D 25	1Φ10 - 100	Φ10 - 200
9	BK3	250	450	3 D 25	2 D 25	1Φ10 - 100	Φ10 - 150
10	BT1	250	450	3 D 16	2 D 16	1Φ10 - 100	Φ10 - 150
11	BT2	250	450	3 D 16	2 D 16	1Φ10 - 100	Φ10 - 150

3.2 Modeling

The modeling of the BPBD building structure was carried out using the ETABS V.22 software in a 3-dimensional model, as shown in Fig. 2, where the beams and columns were modeled as element frames, and the floor was modeled as element slabs, while the walls were input as additional distributed dead loads on the beams.

To analyze the building structure of the BPBD office building, the standard regulations used are SNI 2847:2019 for Structural Concrete Requirements for Buildings, SNI 1726:2019 for Earthquake Resilience Planning Procedures for Buildings and Non-Buildings, and SNI 1727:2020 for Minimum Loads for the Design of Buildings and Other Structures.

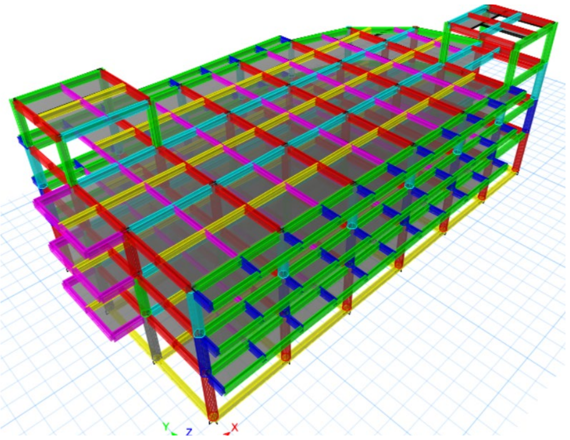

Fig.2 3D modeling of the BPBD building on ETABS

3.3 Response Spectrum Design

The design response spectrum was developed according to SNI 1726:2019, using seismic hazard data from PUSGEN 2019–2020 for Padang city (soil class SD). The short-period spectral acceleration (Ss) is approximately 1.54 g, and the one-second period spectral acceleration (S1) is 0.62 g. With site coefficients Fa = 0.80 and Fv = 2.0, the maximum considered earthquake parameters become SMS ≈ 1.23 g and SM1 ≈ 1.24 g, resulting in design values SDS ≈ 0.82 g and SD1 ≈ 0.83 g. These parameter data were used to generate the design spectrum in ETABS for both principal directions. The primary hazard considered in this study is earthquake loading. Tsunami-induced hydrodynamic loads, while relevant for coastal facilities, were not included in this numerical study and are recommended for future multi-hazard evaluations.

3.4 Loading

The load cases defined in the ETABS model consisted of dead load (DL), live load (LL), and earthquake load (EQX, EQY) applied in both positive and negative directions. These loads were combined according to the load combinations prescribed in SNI 2847:2019 and SNI 1727:2020, such as 1.2DL + 1.6LL + 0.5EQ, and 1.2DL + 1.0EQ + 0.5LL. This ensured that both gravitational and seismic actions were captured in accordance with code requirements.

4. RESULTS AND DISCUSSION

4.1 Analysis of the Existing Building's Structure

4.1.1 Inter-story drift

The determination of inter-story drift must be calculated as the difference in displacement at the center of mass above and below the level under review. Based on calculations of inter-story drift in SNI 1726: 2019, inelastic story drift $\Delta = \delta * Cd / Ie$ and drift limit, $\Delta a = 0.015$ h in terms of X-direction and Y-directions. Based on the results of the analysis (Table 3), the value of inter-story drift on the 2nd floor exceeded the permit limit determined by SNI 1726:2019, namely $\Delta X = 51.150$ mm and $\Delta Y = 46.816$ mm, greater than the drift limit of 41.538 mm. This shows that the existing structure has not met the requirements for the intersection between floors, so it needs to be retrofitted.

Table 3. Results of inter-story drift in the building

Story	h (mm)	Inelastic Drift		Drift Limit (mm)	Check
		Δ_X (mm)	Δ_Y (mm)		
4	3000	23.445	23.650	34.615	OK
3	3600	37.217	33.216	41.538	OK
2	3600	51.150	46.816	41.538	NOT OK
1	4600	51.671	47.542	53.077	OK

4.1.2 Load-bearing capacity of the column

From the results of the structural analysis, a diagram of column interaction was obtained, as seen in Figs. 3-7. From these figures, it can be seen that there are columns that do not have sufficient capacity to withstand the applied loads (K1 and K2) because the moment and axial values (in the form of points) exceed the P-M interaction diagram.

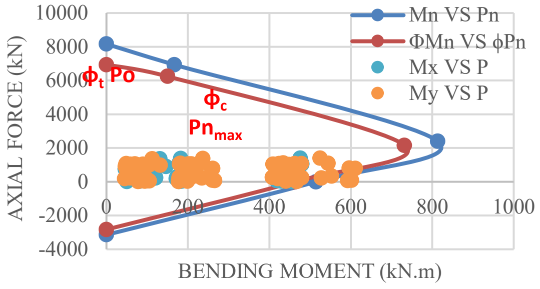

Fig.3 K1 P-M column interaction diagram

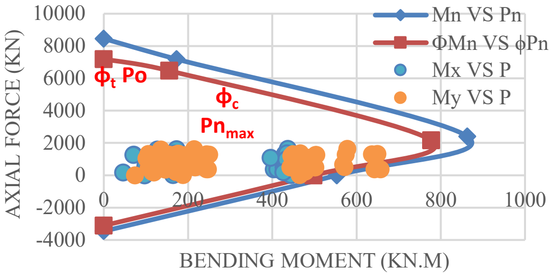

Fig.4 K2 P-M column interaction diagram

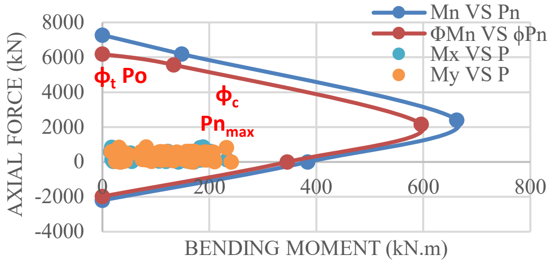

Fig.5 K3 P-M column interaction diagram

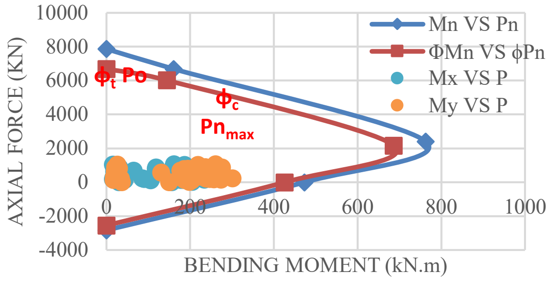

Fig.6 K4 P-M column interaction diagram

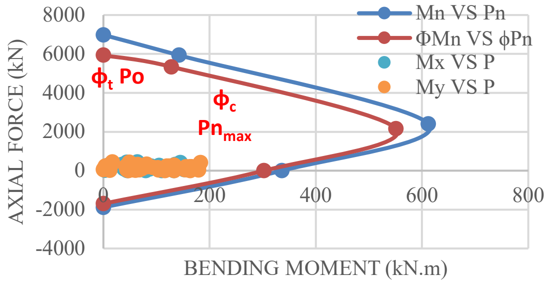

Fig.7 K5 P-M column interaction diagram

4.1.3 Load-bearing capacity of the beam

The results of the beam capacity analysis (Table 4) indicate that, in terms of flexural strength, most elements are still able to withstand the design moment, so they can be considered relatively safe in bending. However, in the shear aspect, several critical beams, particularly B3 and B2a on the second floor and B3b on the third floor, exhibit shear demand (Vu) that exceeds their factored shear capacity (ϕVn). This condition confirms that the main weakness of the existing beams lies not in flexural capacity but in shear resistance, meaning that these elements do not meet the minimum shear strength requirements stipulated in SNI 2847:2019 (article 22.5). Consequently, the insufficient shear resistance significantly increases the seismic vulnerability of the overall structure.

Table 4. Existing beam capacity

Story	Code	ϕMn kNm	Mu kNm	Control ϕMn ≥ Mu	ϕVn kN	Vu kN	Control ϕVn ≥ Vu
2	B1	243.9	120.3	OK	146.8	127.1	OK
	B2	243.9	130.2	OK	146.8	146.8	OK
	B3	302.1	135.5	OK	131.9	171.1	NO
	B1a	243.9	120.3	OK	146.8	78.2	OK
	B2a	243.9	139.6	OK	146.8	151.8	NO
	Ba1	97.5	68.9	OK	114.7	49.8	OK
	Ba2	44.9	22.5	OK	65.3	39.5	OK
	Ba3	44.5	13.0	OK	83.0	22.0	OK
	BK1	125.6	117.9	OK	168.3	115.9	OK
	BK2	48.0	4.0	OK	100.0	2.4	OK
	BK3	109.9	55.9	OK	126.0	55.4	OK
	BT1	70.2	22.0	OK	100.0	21.4	OK
	BT2	70.2	57.3	OK	100.0	50.2	OK

4.1.4 Floor slab bending capacity

The floor slab in the BPBD office building is a 2-way slab where the width of the direction x is 3 m, equal to the width of the direction of y, which is also 3 m, so that the ratio of the width of the direction x and the width of the direction y is less than 1.

Table 5. Floor slab bending capacity

Description	Reinforcement	
	X Dir.	Y Dir.
Load combination	EQX load	EQY load
Outside Moment (tm/m)	2.515	1.6157
Upper reinforcement	D10-250	D10-250
Bottom reinforcement	D10-250	D10-250
Nominal Moment (tm/m)	0.887	0.887
Check Nominal Moments > External Moments	Not Ok	Not OK

From Table 5 above, it can be seen that the flexural capacity of the floor slab is still smaller than the external moment due to the working load, indicating that the condition of the slab is unsafe.

4.1.5 Fragility Curve

The fragility curve is a log-normal function that represents the probability of a structure exceeding specific damage states by considering uncertainties in structural capacity, seismic demand, and damage criteria [11-12]. It describes the relationship between the probability of structural damage and the level of seismic hazard expressed through an intensity measure.

In this study, an analytical approach was employed to develop seismic fragility curves for the building in both existing and retrofitted conditions under earthquake loading. The selected intensity measure (IM) is peak ground acceleration (PGA), which is widely used to represent seismic demand. The parameters required to construct the fragility curves were derived from nonlinear structural analyses. Yield drift values were obtained from pushover analysis, while maximum drift demands were extracted from nonlinear time-history analysis [13].

The resulting fragility function parameters serve as the basis for developing the seismic fragility curve of the existing building, as summarized in Table 6.

Table 6. Parameters for seismic fragility functions

Damage level	β_d	Bc	λ_c	ζ_c
Slight Damage	0.12	0.25	-2.43	0.28
Moderate Damage	0.12	0.25	-1.74	0.28
Extensive Damage	0.12	0.47	-0.64	0.49
Complete Damage	0.12	0.47	0.34	0.49

Fig. 8 indicates that the existing building exhibits high seismic vulnerability. The fragility curves for slight and moderate damage are located on the left side, showing that even at relatively low PGA levels, the probability of moderate damage is already very high. Meanwhile, the probabilities of extensive and complete damage increase significantly at moderate to high PGA values, reflecting the limited lateral stiffness and structural capacity of the existing building.

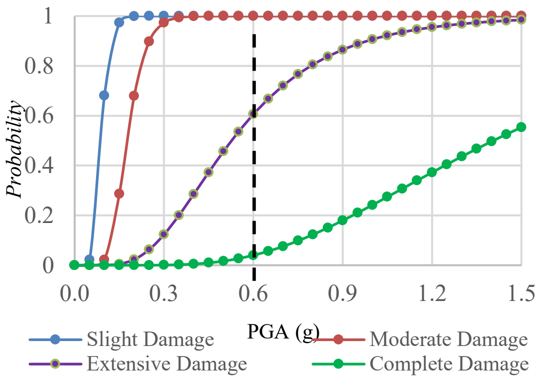

Fig.8 Seismic fragility curve of the existing building

Table 7. The damage probability percentage of the building during an earthquake

Damage level	Percentage of probability
Slight Damage	100 %
Moderate Damage	99.9 %
Extensive Damage	60.5 %
Complete Damage	4.0 %

Table 7 further confirms these findings, where at a PGA of 0.6 g the probabilities of slight and moderate damage are almost 100%. In addition, the probability of extensive damage remains relatively high at 60.5%, while complete damage reaches 4.0%. These results indicate that the existing structure does not provide adequate seismic performance and is prone to significant damage under strong earthquake loading.

4.2 Structural Retrofitting Analysis

Based on the results of the evaluation of the existing structure, it is known that some key elements, such as columns and beams, are not fully able to withstand the workload, coupled with the deviation between floors that exceeds the permitted limit. This condition emphasizes the need for comprehensive strengthening efforts. The method chosen is the installation of a shear wall, as this technique has proven to be effective in increasing the global rigidity of the building, lowering the deviation between floors, and reducing the internal force on structural elements. Subsequently, the retrofitted building was reanalyzed to ensure that it achieved the minimum required strength of the building.

4.2.1 Retrofitting of the building using shear walls

The placement of shear walls in existing buildings is determined by considering the dominant direction of earthquake forces, spatial function, and the need to minimize eccentricity between floors. The selected location is focused on the weak axis of the building so that it can optimally increase lateral rigidity without disturbing the spatial layout. With this configuration, the torque moment on the structure can be suppressed, and the distribution of the earthquake force to the structural elements becomes more even. The shear wall used has a concrete quality of 30 MPa and is installed as high as the existing building, so that it can function as the main strengthening element while transforming the structural system into a dual system. The location of the shear wall placement is shown in Fig. 9.

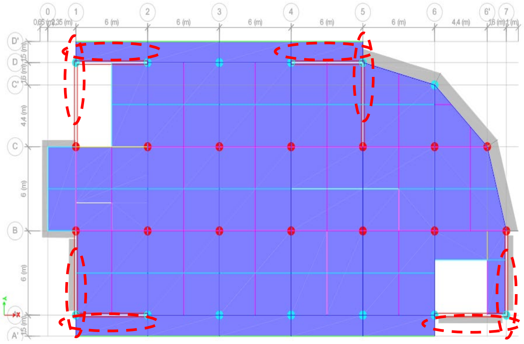

Fig.9 Location of shear wall placement

Through retrofitting of the structure with shear walls, a transformation occurs in the building's structural system, transitioning into a dual system. This alteration affects earthquake parameters, including the adjustment of the response modification coefficient (R) to 7, the over-strength factor system (Ω) to 2.5, the building period coefficient (Ct) to 0.0466, and the period parameter (x) to 0.9.

4.2.2 Analysis result of the retrofitted building using shear walls

The re-analysis of the building after being given a shear wall was carried out using the same procedure as in the existing structure, but earthquake parameters were used for the dual system due to the addition of shear wall elements.

Table 8. Inter-story drift of the retrofitted building

Story	h (mm)	Inelastic Drift		Drift Limit	Check
		$\Delta_{X\,(mm)}$	$\Delta_{Y\,(mm)}$		
4	3000	16.691	16.654	23.077	OK
3	3600	1.456	1.584	27.692	OK
2	3600	1.577	1.749	27.692	OK
1	4600	1.456	1.584	35.385	OK

After the installation of the shear wall, the value of inter-story drift on the entire floor has decreased significantly (Table 8) and is below the SNI 1726:2019 permit limit. This shows that retrofitting has succeeded in increasing the lateral rigidity of the building, so that the deviation between floors can be controlled well and the structure becomes more stable against earthquake loads.

A re-analysis showed that the entire column after installing the shear wall had adequate capacity, as indicated by the axial load points and moments that were still within the P-M interaction curve (Figs. 10-14). The addition of a shear wall also lowers the force in the columns, with the reduction in moment and shear reaching more than 80% at K1, K2, and K3, while axial reaching more than 30 % at K1, K3, and K5. The greatest reduction in force occurred in column K1 with a decrease in moment of 95%, shear of 93%, and axial of 30%. This condition confirms that retrofitting is able to increase the ability of the column to withstand earthquake loads and maintain structural stability.

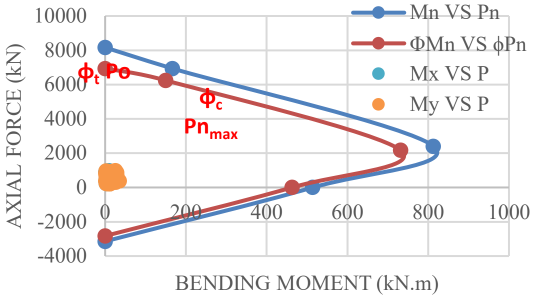

Fig.10 K1 P-M column interaction diagram after retrofitting

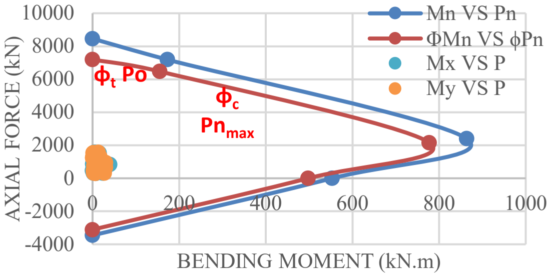

Fig.11 K2 P-M column interaction diagram after retrofitting

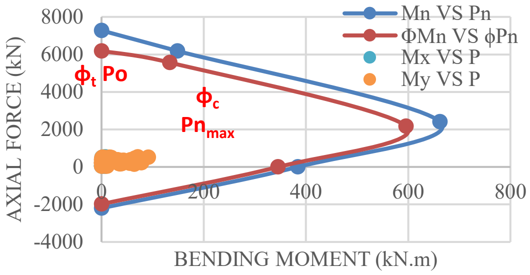

Fig.12 K3 P-M column interaction diagram after retrofitting

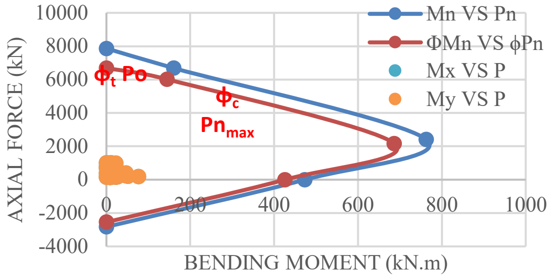

Fig.13 K4 P-M column interaction diagram after retrofitting

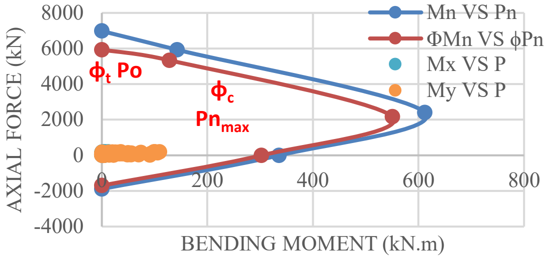

Fig.14 K5 P-M column interaction diagram after retrofitting

After the installation of the shear wall, the beam capacity showed a significant increase. The results of the analysis showed that all beams were able to withstand the moment and shear force according to the provisions. The decrease in inner force is also quite large, with a maximum moment reduction of about 81% (Ba3) and a shear force of up to 63% (BT2). This proves that shear wall retrofitting is effective in improving beam performance and reducing the potential for damage due to earthquake loads.

In addition to the structural capacity improvements demonstrated by the numerical analysis, the practical implementation of shear wall retrofitting in existing buildings also presents significant challenges. The installation of shear walls requires careful construction phasing to minimize disruption to building operations. For the BPBD office building, phasing strategies must be designed to allow temporary closure of certain areas without interrupting critical functions. Furthermore, building occupancy management during the retrofit is crucial to ensure user safety. This may include zoning of construction areas, temporary evacuation of floors under strengthening, and strict enforcement of safety procedures. These considerations highlight that the success of retrofitting is determined not only by compliance with analytical design requirements but also by effective management of on-site construction logistics.

4.2.3 Retrofitting of slab using FRP

The flexural retrofitting of the floor slab given with Fiber Reinforced Polymer (FRP) is carried out by providing additional FRP as follows.

1. Retrofitting of the field reinforcement is carried out by applying FRP to the bottom of the floor slab (Fig. 15)
2. The retrofitting of the support reinforcement is carried out by applying FRP to the top of the floor slab (Fig. 16).

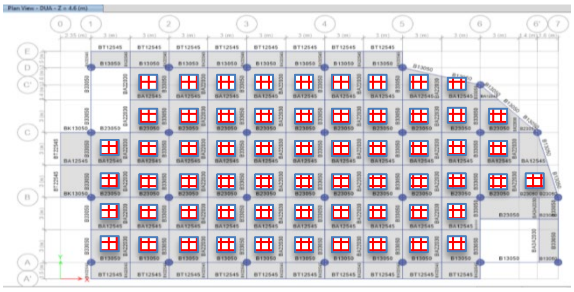

Fig.15 FRP installation of the second-floor slab field

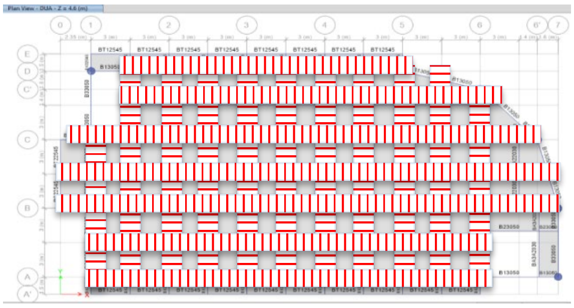

Fig.16 Installation of FRP retrofitting of the focus of the second floor slab

The analysis shows that after flexural strengthening with FRP sheets, the slab's moment capacity increased from 0.89 t.m to 2.62 t.m. This value exceeds the external moment of 2.51 t.m, confirming that the retrofitted slab can safely resist bending loads. Thus, FRP retrofitting effectively improves slab performance and reduces the risk of failure under seismic demands.

4.2.4 Fragility curve of the retrofitted building

The seismic fragility function parameters obtained from the calculation results are used as a basis for developing the seismic fragility curve of the existing building, as presented in Table 9.

Fig. 17 illustrates the seismic fragility curve of the retrofitted building. The earthquake fragility curve is categorized into four damage levels, ranging from slight damage to complete damage. Table 10 presents the probability of damage levels of the retrofitted building structure subjected to an earthquake with a PGA value of 0.6 g.

Table 9. Parameters for seismic fragility functions of the retrofitted building

Damage level	βd	Bc	λ_c	ζ_c
Slight Damage	0.71	0.25	-1.33	0.76
Moderate Damage	0.71	0.25	-0.63	0.76
Extensive Damage	0.71	0.47	0.46	0.85
Complete Damage	0.71	0.47	1.45	0.85

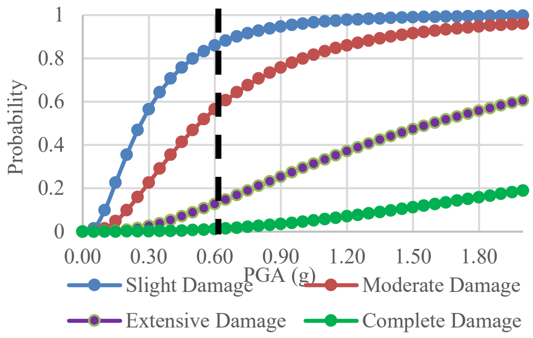

Fig.17 Seismic fragility curve of the retrofitted building

Table 10. The damage probability percentage of the building during an earthquake (retrofitted building)

Damage level	Percentage of probability
Slight Damage	85.95 %
Moderate Damage	56.45 %
Extensive Damage	12.69 %
Complete Damage	1.10 %

The fragility curve analysis indicates a significant reduction in damage probability after the implementation of structural strengthening measures. Prior to retrofitting, the structure exhibited a higher probability of reaching moderate to severe damage states under increasing seismic intensity. However, following the strengthening intervention, the fragility curves shift consistently to the right, demonstrating improved structural capacity and enhanced seismic performance.

For the same level of seismic demand, the probability of exceeding each damage state decreases notably after strengthening. This reduction is particularly evident in the moderate and extensive damage states, where the strengthened structure shows a substantially lower likelihood of damage occurrence compared to the original condition. The results confirm that the applied strengthening measures effectively increase the resistance and ductility of the structure, thereby mitigating seismic vulnerability.

Overall, the observed decrease in damage probability derived from the fragility curves confirms the effectiveness of the strengthening strategy in reducing seismic risk and improving the structural reliability under earthquake loading.

5. CONCLUSION

Based on the results of the assessment and analysis of the retrofitting of the West Sumatra Province BPBD Office Building, it can be concluded that:

1. The existing structure does not meet the requirements of inter-story drift, and some of the columns show weakness in the moment and axial capacity, and several beams show weakness in the shear capacity, so the building is not completely safe against earthquake loads.
2. The installation of shear walls was chosen as a retrofitting method because it was able to increase the global rigidity of the building, reduce the deviation between floors, and reduce the internal force on structural elements.
3. Re-analysis after retrofitting showed that all column and beam elements had met the strength requirements, with a significant reduction in force in the column, which was up to 95% moment, 93% shear, and 30% axial (K1), as well as about 81% at the moment and 63% at the beam shear. With the shear wall, the performance of the structure meets the provisions of SNI so that the building becomes more stable, safe, and suitable to function as a BPBD operational office in earthquake-prone areas.
4. After being strengthened with FRP, the flexural capacity of the floor slab increased from 0.89 t.m to about 2.62 t.m, so that it was able to surpass the external moment that occurred of 2.51 t.m. This shows that retrofitting with FRP effectively improves the performance of the slab in resisting bending loads.

5. The fragility curve analysis confirms that the addition of shear walls significantly reduces the probability of damage under seismic loading. After retrofitting, the structure shows consistently lower damage probabilities across all damage states, indicating improved stiffness, strength, and overall seismic performance. These results demonstrate that shear wall strengthening is an effective and reliable strategy for reducing structural vulnerability to earthquakes.
6. Although the analytical results confirm that the combined retrofitting strategy using shear walls and FRP significantly enhances seismic performance, practical implementation challenges must also be addressed. Key issues include planning construction phasing to allow building operations to continue, managing occupancy during retrofit to ensure safety, and maintaining strict quality control in both shear wall casting and FRP installation. Therefore, the effectiveness of the proposed retrofitting solution can only be fully achieved when accompanied by well-prepared implementation planning in real conditions.

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