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Seismic performance comparison of existing public facilities strengthened with RC jacketing and steel bracing

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Abstract. Banda Aceh is one of the areas that sustains the most damage during a natural disaster because it contains so many houses, office buildings, public facilities, and schools. Public structures in coastal areas are highly susceptible to earthquakes, resulting in high casualties and property damage. Several public structures were reconstructed during the reconstruction and rehabilitation period. Because this building is located in an area with a high risk of earthquakes, its capacity must be analyzed initially. Additionally, history indicates that Aceh Province has been struck by numerous earthquakes, including the largest ever recorded in 1983 and the most recent earthquake with a magnitude of 9.3 SR on December 26, 2004. The city of Banda Aceh was devastated by this earthquake, which was followed by a tsunami. The possibility of a large earthquake in Banda Aceh City necessitates that the structures constructed there be resistant to seismic risk. This study's objective was to evaluate the seismic performance of the existing building by applying the method of strengthening the structure in the form of jacketing columns and the addition of steel bracing in order to estimate the performance of the structure using multiple ground motions. Therefore, several public buildings must be analyzed to determine the optimal seismic retrofitting technique.

Keywords: displacement; earthquake; ground motions; RC jacketing; retrofitting; steel bracing

1. Introduction

The Banda Aceh region is susceptible to earthquakes. According to Sugiyanto *et al.* (2011), This is because Banda Aceh City is situated between two active faults, namely the Aceh segment and the still-active Seulimum segment. In 2004, a 9.3-magnitude earthquake followed by a tsunami devastated Banda Aceh City, according to historical records. Damage was caused to structures and infrastructure, public facilities, and other buildings by the earthquake and tsunami. In light of past disasters, it is essential to ensure that the planning, construction, and operation of a building adhere to earthquake and building codes. The Indonesian building standards for earthquake-resistant design and tsunami loading are based on SNI 1726-2019 and SNI 1726-2020, which discuss building loads in detail. In the planning, construction, and operation of public buildings, such as mosques and schools, the application of planning regulations and standards has commenced. There is a need for safety and disaster preparedness due to the occurrence of disaster-related losses. Wiryanto (2005) have studied the safety and security of buildings is dependent not only on the level of strength, but also on the deformation and energy of the structure's performance. It is crucial to conduct a feasibility study on the earthquake resistance of existing public buildings because they are used for disaster preparedness.

In addition, the demand for reinforcing reinforced concrete (RC) columns in buildings and infrastructure has increased gradually due to the deterioration of their structural performance as a result of unanticipated problems such as corrosion of steel reinforcement, earthquake damage, inadequate design, and premature carbonation of concrete has been described by Yong-Ha *et al.* (2020). Particularly, older structures that were designed in accordance with seismic codes that are less stringent than the current revised codes require adequate strengthening to improve the stiffness, strength, and ductility of columns, as severe damage has frequently been observed in such structures during medium- or large-scale earthquakes (Faustino and Chastre 2005)

Furthermore, numerous studies on the vulnerability of public buildings to earthquakes when retrofitted have been conducted. According to research conducted by Requena-García-Cruz *et al.* in 2019, her findings indicate that implementing techniques with a reduced architectural impact yields and satisfactory results. The analysis of the mean damage level index revealed that the structure would sustain significant damage. All applied retrofitting techniques have at least reduced it to moderate damage. Additionally, it is important to note that the position of the retrofitting elements is also crucial for achieving optimal retrofitting.

Segovia-Verjel *et al.* in the same year also conducted a study on retrofitting and the results showed that the addition of encirclements has reduced the deformation of the

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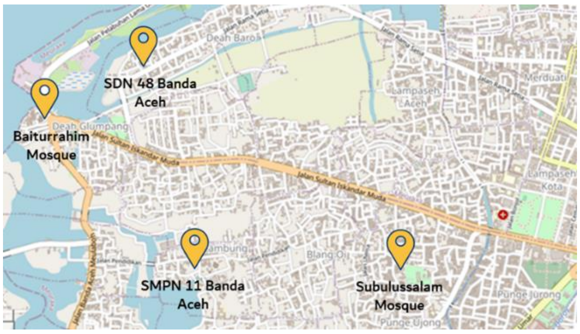


Fig. 1 Map of the distribution of public buildings that are the object of research

structure, resulting in a slight increase in its stiffness. The addition of steel grids has produced the greatest increase in peak strength, while the addition of polymer grids has produced the greatest ultimate displacements. The best cost-to-benefit ratio was achieved by adding encirclement.

In addition, in 2020 the results of research from Romero-Sánchez *et al.* showed that the combination of reinforcements has been made with structural and architectural impact and constructional parameters in imagination. Calculations indicate that steel *X*-bracings are the most effective method for preventing the formation of a soft floor on the ground floor. In the models with *X*-bracing in the ground floor and steel jackets in the upper floor, the potential of structural damage or deformation has been improved significantly. In addition, when steel *X*-bracing is used in the ground floor, the deformation of the its upper-floor columns increases. Utilizing steel jackets has proven to be the best solution for the short columns on the upper floors. The results indicate that this combination significantly reduces the expected overall damage level. The resulting retrofitting strategy can be extrapolated to other structures of a similar type.

Effective and efficient seismic retrofitting can decrease the seismic vulnerability of structures. Consequently, based on the aforementioned hypothesis, a study will be conducted on the evaluation of seismic performance in public buildings dispersed throughout the Meuraxa District of Banda Aceh City using the retrofit column jacketing method and the addition of steel bracing. Using multiple ground motions, this reinforcement method is used to predict and estimate the performance of the structure. This research intends to investigate the effectiveness of various seismic retrofitting techniques in reducing the seismic vulnerability of public buildings.

2. Research data

2.1 Research object

This research focuses on the use of finite elements to strengthen existing buildings. Existing structures are those that are either undergoing construction or are already in use. This study examines the existing structures scattered throughout Meuraxa District in Banda Aceh City. For this study, buildings with a particular structural type,

(a) SDN 48 Banda Aceh

(b) SMPN 11 Banda Aceh

(c) Baiturrahim Mosque

(d) Subulussalam Mosque

Fig. 2 The buildings that are the object of review in this study

one of the most prevalent in the study area, were chosen. This Reinforced Concrete (RC) frame structure has been extensively used for public activities such as schools and mosques. As a result, the seismic retrofitting results are more significant and easier to extrapolate to other buildings of a similar type. The distribution of these structures is depicted in Fig. 1.

This study examines public structures including SDN 48 Banda Aceh, SMPN 11 Banda Aceh, Baiturrahim Ulee Lheu Mosque, and Subulussalam Punge Mosque. These structures are essential to evaluate because they are utilized in disaster mitigation efforts and as public spaces. Fig. 2

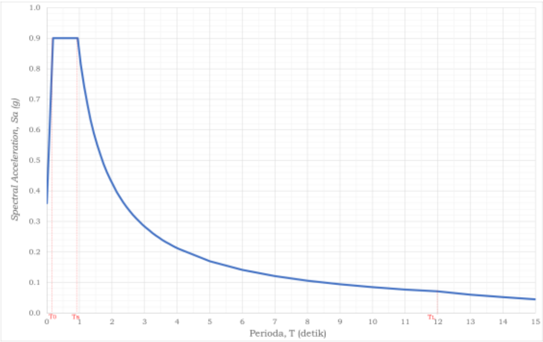


Fig. 3 Meuraxa district target spectrum response

shows the current structure that is the subject of the study.

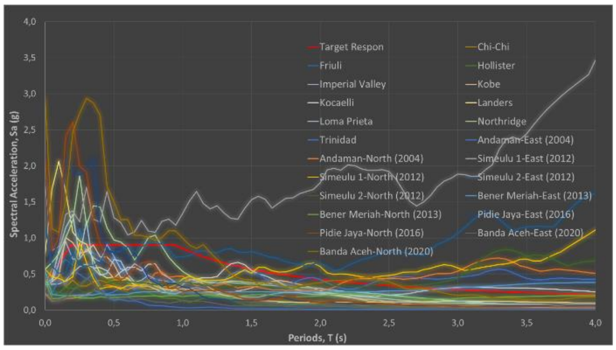
The process of inventorying the condition of the building is accomplished through direct inspections of existing buildings dispersed throughout the Meuraxa District of Banda Aceh. The inventory procedure begins with an assessment to collect data regarding the condition of the existing structure based on field data. The collected data pertains to the physical condition of the building, including building plans, quality of materials used, dimensions of structural components, and detailed dimensions, as well as building damage. The equipment used to determine the condition of a building, such as the profometer, hammer test, and laser meter, is referred to as the supporting equipment for building evaluations.

2.2 Response spectrum target

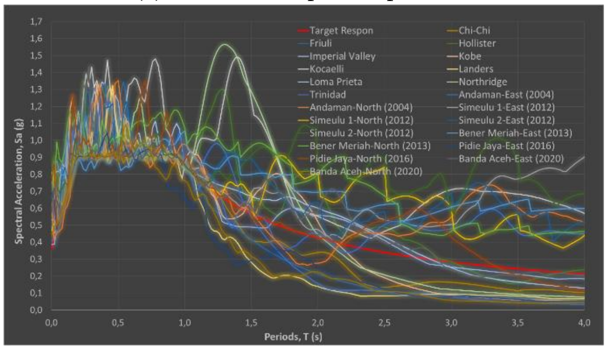
According to the Earthquake Source and Hazard Map (PuSGeN 2017), the earthquake load indicated in the earthquake SNI is a spectrum response. The rules for determining the spectrum response can be found in SNI 1726-2019. Based on SNI 1726:2019, the parameters Ss (bedrock acceleration in a short period) and S1 (bedrock acceleration in a period of 1 second) must be determined from the acceleration spectral response of 0.2 seconds and 1 second in the seismic ground motion map with the possibility of 2 percent exceeded in 50 years (MCER, 2 percent in 50 years) and the TL parameters were determined from the long-period transition map, and expressed in decimal numbers with respect to the Ss parameter. Fig. 3 depicts, according to SNI 1726:2019, the spectrum response in the Meuraxa District of Banda Aceh City.

2.3 Ground motions records

Data collected on ground motions represent earthquakes that have occurred and severely damaged building structures. In addition to earthquake data from the Aceh region, several records of earthquake data from outside the Aceh region were utilized in this study. As shown in Table 1, 22 earthquake records will be utilized in this study. Afterward, using the DADiSP/SE 6.7 software, the ASCII-formatted waveform of ground motion data was transformed into an accelerogram. Using seismosignal software, the accelerogram is converted into a response spectrum.



(a) Unscaled response spectrum



(b) Scaled response spectrum

Fig. 4 Matching response spectrum. Adjustment of the accelerogram response spectrum with the target spectrum response using Seismomatch

3. Methods

3.1 Matching response spectrum

With the aid of seismosignal software, accelerogram-based earthquake data is converted into a response spectrum. The calculation of the scale factor compares the spectral acceleration value of the ground motion records response spectrum to the spectral acceleration value of the target response spectrum. The spectral acceleration value used to calculate the scale factor is only between $0.8T_{Lower}$ and $1.2T_{Lower}$, where T is the first natural period of the under consideration building structure.

In order to match ground motion records to the target response spectrum, the method of spectral matching is used to modify the frequency content. Using a scale factor to adjust the ground motion record to the target response spectrum. The scale factor (SF) is calculated using the following formula from Kalkan and Chopra (2010)

$$SF = \frac{\sum_{i=1}^{n} \bar{A}\mathrm{Ai}}{\sum_{i=1}^{n} \mathrm{AiAi}} \tag{1}$$

with

SF=scale factor,

Ā=Spectral acceleration target,

Ai=Spectral acceleration scaled

The scaled accelerogram is entered into SAP2000 as a load with the scale factor=g I/R, where g=acceleration due to gravity (9.81 m/s2), I is the main earthquake factor, which is 1.5 for a building risk categorized as number IV (important building for disaster mitigation), and R is an 8-

Table 1 Table list of ground motion records used

Earthquake	Magnitude	Earthquake	Magnitude
Chi-Chi (Taiwan)	7,3	Andaman-North 2004	9,3
Friuli (Italia)	6,5	Simeulu 1-East 2012	8,5
Hollister (USA)	5,6	Simeulu 1-North 2012	8,5
Imperial Valley (USA)	6,5	Simeulu 2-East 2012	8,1
Kobe (Japan)	6,9	Simeulu 2-North 2012	8,1
Kocaeli (Turkey)	7,4	Bener Meriah-East 2013	6,1
Landers (USA)	7,3	Bener Meriah-North 2013	6,1
Loma Prieta (USA)	6,9	Pidie Jaya-East 2016	6,5
Northridge (USA)	6,7	Pidie Jaya-North 2016	6,5
Trinidad (USA)	6,7	Banda Aceh-East 2020	5,5
Andaman-East 2004	9,3	Banda Aceh-North 2020	5,5

Source: www.peer.berkeley.edu dan BMKG database

factor reduction coefficient factor. Fig. 4(a) depicts a comparison of the unscaled response spectrum of various ground motion records with the target response spectrum, while Fig. 4(b) depicts a comparison of the scaled spectrum response.

3.2 Modelling structure and structure loading

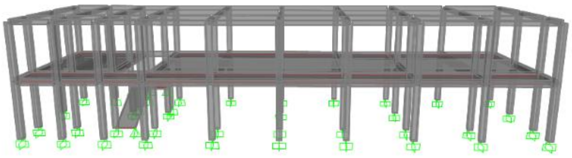
Four public structures in the Meuraxa District were modeled using structural analysis and finite element. Space frame is the form of the structural system that will be modeled in SAP2000 using finite elements. Furthermore, dead loads, live loads, and earthquake loads are the types of loads reviewed in structural planning that are inputted into the SAP2000 program. To determine the ultimate load based on the loads that may occur on the structure, a combination of factored loads is performed in accordance with SNI 1726-2019. Dead loads, live loads, and earthquake loads are the types of loads reviewed in structural planning that are inputted into the SAP2000 program. The SAP2000-modeled space frame is then loaded with the resulting calculation of these loads. Earthquake load utilized in this study is earthquake load with time history analysis using data on ground acceleration resulting from multiple earthquakes, as shown in Table 1.

3.3 Retrofitting with column jacketing

Popular method for retrofitting RC structural members is RC jacketing. This is primarily due to the fact that while it can effectively improve the mechanical performance of structural members, it also has a number of other advantages over steel or fiber-reinforced polymer composite jackets, such as high durability, adequate fire and corrosion resistance, a simple construction technique, and a wide availability of construction materials (Fatih 2004, Giovanni *et al.* 2010, Souza and Appleton 1997, Diab 1997, Vandoros and Dritsos 2008, Tsonos 2010). Jacketing is a well-known rehabilitation technique for damaged or improperly detailed reinforced concrete members that provides increased strength, stiffness, and overall structural performance improvement has been described by Bousias *et al.* (2007). Existing inadequate or damaged structural elements have been evaluated with jackets made from conventional cast-in-place concrete (Vandoros and Dritsos 2008), premixed, non-shrink, flowable, rapid and high-strength cement-based mortar (Karayannis *et al.* 2008), shotcrete (Tsonos 2010), Textile-Reinforced-Mortars (Triantafillou and Papanicolau 2010) and Fibre-Reinforced-Polymers (Triantafillou and Papanicolaou 2006).

Reinforced concrete (RC) is used extensively as a building material in both developing and developed nations' urban cores and remotest regions. Before reaching their intended design life, structures made with this material frequently sustain damage from overloading, natural disasters (such as earthquake, Tsunami, Cyclone, Flood, etc.), fire, various environmental effects (such as corrosion), changes in building usage, etc. (Kaish 2012). These damages may result in structural components failing to meet the functional requirements for their designed service life. If proper care is not taken in this regard, the entire structure may not be able to support its design load, which could result in a catastrophe. In addition, the results of research from Mieczyslaw and Tomasz (2006) showed that one of the failures of the most important structural element, such as a column, may result in the total collapse of a frame-structured building, as it is the only structural element that transfers the building's vertical loads to the ground. This member could lose its strength and stiffness due to service-related damage. A building's mechanism for collapsing depends not just on its columns but also on how the structure was designed and how sturdy it was. In order for a structure to continue carrying loads and transmitting them to the ground, repair or reconstruction is required in the event of a visible crack.

Restrengthening the column is one of the cutting-edge methods used to carry structural loads by a column that is partially damaged. Replacement of structurally weak concrete; the fiber warps technique; and external jacketing are typically used to re-strengthen RC columns based on their application (CPWD 2002). It is necessary to remove deteriorated concrete and pour new concrete in the same



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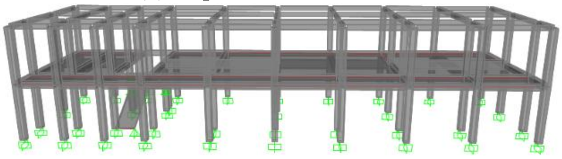

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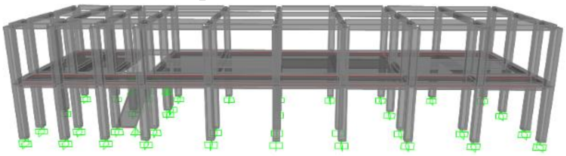

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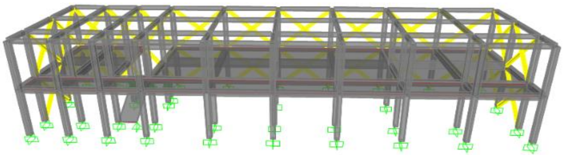
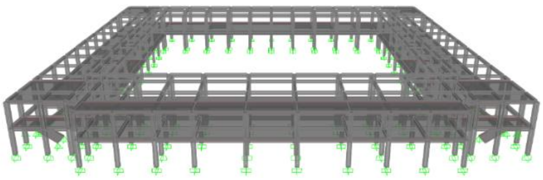


(d) Bracing

Fig. 5 Retrofitting modelling for SDN 48 Banda Aceh



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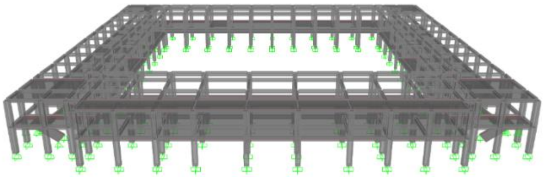

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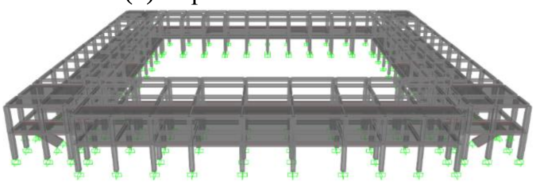

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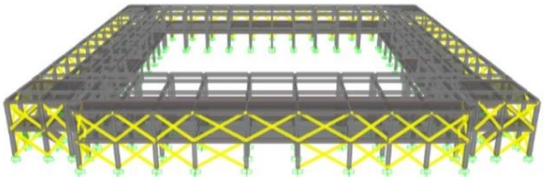
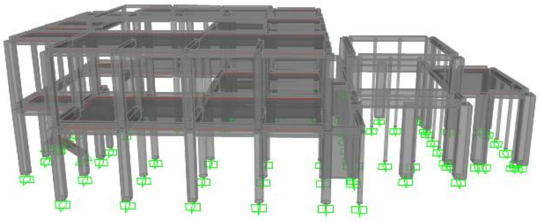


(d) Bracing

Fig. 6 Retrofitting modelling for SMPN 11 Banda Aceh

location in order to replace concrete that is structurally weak. The fiber warps technique for re-strengthening RC columns requires external warping with reinforced plastic fibers. Restrengthening RC columns with external jacketing relies on the well-established fact that lateral confinement of the concrete core significantly increases its compressive strength and ultimate axial strain according to Riad *et al.* (2008). As a structural column in this study's column jacketing method, the proportional area of the primary column is used. 10%, 20%, and 40% are the respective percentages of the expanded column.



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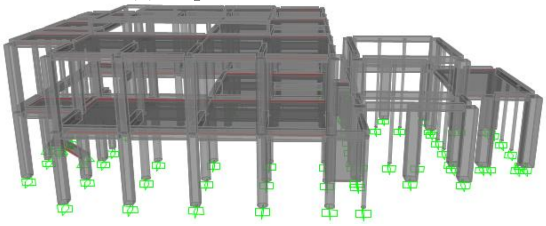

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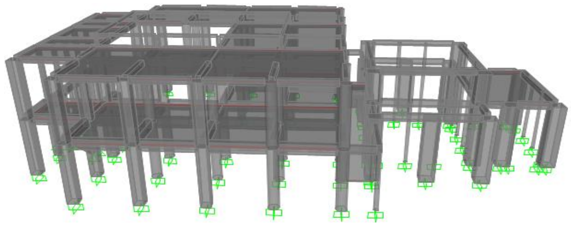

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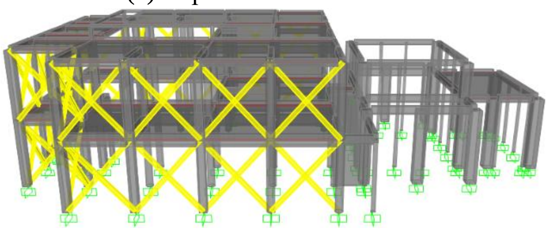
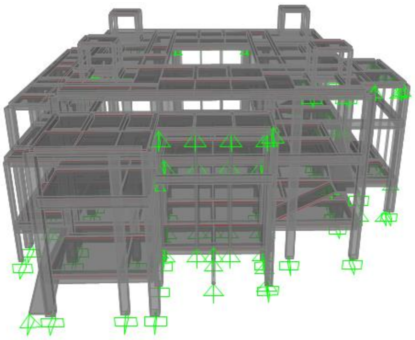


(d) Bracing

Fig. 7 Retrofitting modelling for Baiturrahim mosque

3.4 Retrofitting with steel bracing

Bracing is a strengthening technique of reinforced concrete that allows the primary components to function optimally and become a single unit when earthquake loads are applied. Widespread use of bracing has been made to strengthen building structures. In addition to reinforced concrete and steel, bracing consists of a variety of other materials. According to Aryandi and Herbudiman (2017), Combining the structure with bracing stiffening elements is one way to increase the structure's stability. Adding braced frame elements primarily serves to reinforce the structure so that deformation from inter-story drift can be reduced. Braced frame elements are diagonally placed structural elements on the frame structure that support the portal



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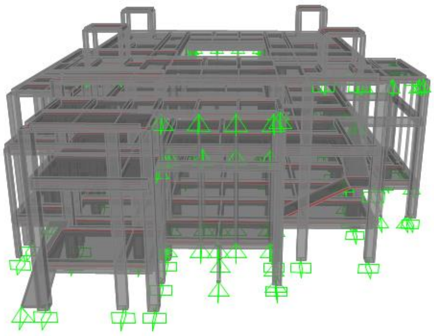

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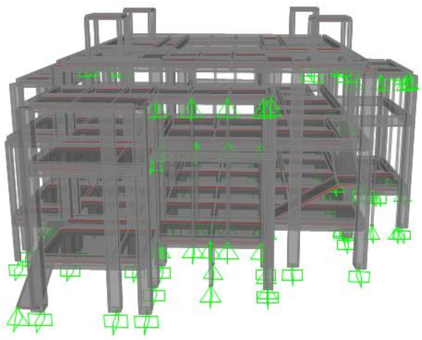

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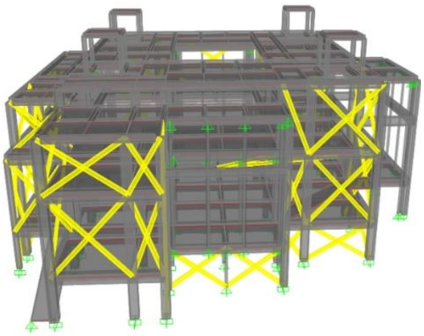


(d) Bracing

Fig. 8 Retrofitting modelling for Subulussalam mosque

against lateral loads. Based on the research from Badoux and Jirsa (1990), depending on the design concept, steel or reinforced concrete can be used to construct stiffeners. Steel bracing systems are typically implemented to ensure the structural stability and seismic resistance of steel storage pallet racks, the height of which has increased steadily in recent years to improve warehouse productivity (Federico *et al.* 2019).

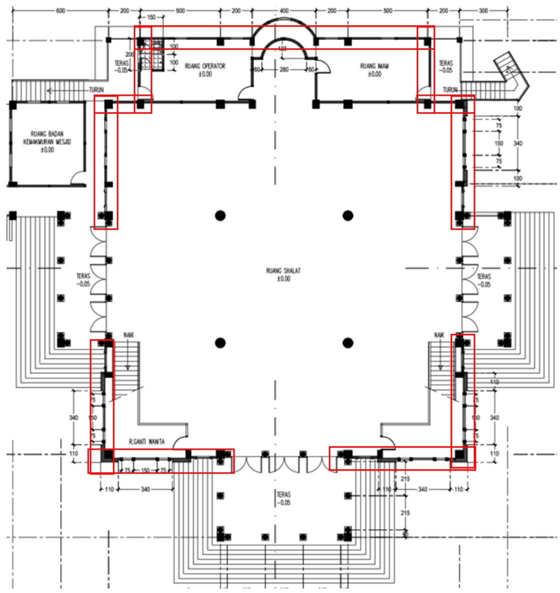


Fig. 9 The positions in plan of bracings

According to Sukrawa *et al.* (2016), Bracing on multi-story portal structures is thought to increase the stiffness and strength of the building structure, allowing it to withstand lateral loads caused by wind or earthquakes; additionally, the use of bracing is typically more efficient and cost-effective. The use of steel braces to reinforce the structure has a number of advantages, including a shorter processing time and minimal impact on the structure's weight. This can strengthen the building's overall structure (Bedi and Nagpur 2013). Wide Flange 250 is the used bracing, with the values of yield and tensile strengths being average values, with the following specifications

- E=200.000 Mpa
- W=7850 Kg/cm^3
- Fy=235 MPa
- Fu=400 MPa
- Fye=245 MPa
- Fue=510 MPa
- Outside Height=250 mm
- Top flange Width=125 mm
- Top flange thickness=9 mm
- Web thickness=6 mm
- Bottom flange width=125 mm
- Bottom flange thickness=9 mm

The retrofitting model of the building can be seen in Fig. 5 to Fig. 8.

For bracing in the Fig 8. The position in plan of bracing is conducted on infilled wall, and can be seen in Fig 9. below.

3.5 Time history analysis

A simple definition of dynamic analysis is a change in time. The term "dynamic load" refers to any load whose magnitude, direction, or position changes over time. Clough and Penzien (1997) stated that similarly, the response of the structure to dynamic loads, including the resulting deflections and stresses, as well as temporal changes, or

Table 2 Effective diversity mass participation

Buildings	Tipe Modal	Item	Static (%)	Dynamic (%)
SDN 48 Banda Aceh	Acceleration	UX	100	97.3989
	Acceleration	UY	100	97.6435
SMPN 11 Banda Aceh	Acceleration	UX	100	94.0146
	Acceleration	UY	100	95.027
Baiturrahim Mosque	Acceleration	UX	100	97.0525
	Acceleration	UY	100	96.311
Subulussalam Mosque	Acceleration	UX	100	95.2758
	Acceleration	UY	100	91.6633

Table 3 Fundamental vibration time analysis results

Buildings	Period	Ta requisition
	Sec	Sec
SDN 48 Banda Aceh	0.350	0.3759
SMPN 11 Banda Aceh	0.242	0.4239
Baiturrahim Mosque	0.350	0.5182
Subulussalam Mosque	0.162	0.8089

Table 4 Base shear analysis results of existing buildings

Buildings	V	Base Shear Vt		Description	
	Kgf	Vtx	Vty	Vt>V	
SDN 48 Banda Aceh	17967.477	21399.91	18426.06	Ok	Ok
		18079.09	21796.03	Ok	Ok
SMPN 11 Banda Aceh	145549.477	332090.16	170698.21	Ok	Ok
		149702.42	378665.88	Ok	Ok
Baiturrahim Mosque	54318.684	83492.47	54495.93	Ok	Ok
		74185.27	61332.94	Ok	Ok
Subulussalam Mosque	127908.304	322935.9	128411.8	Ok	Ok
		222807.95	211815.99	Ok	Ok

dynamic properties. Time history dynamic analysis is one of the dynamic analysis techniques utilized in earthquake structural analysis. In time history analysis, earthquake accelerograms must be derived from ground motion records due to earthquakes collected at a location with similar geological, topographic, and seismotectonic conditions. In linear dynamic analysis of the time history of the influence of the design earthquake on the nominal earthquake loading level, the original ground acceleration of the input earthquake must be scaled so that the response spectrum is, on average, close to the level of the rock earthquake response spectrum over a substantial period range. the response of the structure of the building to be designed. Using an equation based on SNI 1726-2019, the time history method will be applied to a combination of seismic loading

$$1.2D + Ev + Emh + L \quad (2)$$

$$0,9D - Ev + Emh \quad (3)$$

After completing the structural modeling, the next step is to input the earthquake history data. Then, conduct a dynamic analysis of time history. The analysis produces displacements in the x and y directions. This displacement value is used to calculate the drift ratio, which is important for structural capacity analysis.

4. Results and discussions

4.1 The results of the dynamic characteristics of the structure

4.1.1 Mass variance analysis results

Modal analysis is used todetermine the effective mass participation of variance (modal load participation ratios), which must be larger than 90%. On this analysis, the modal analysis applies twelve modes. The value of modal analysis is retrieved straight from SAP2000 by selecting in the display table, these values of reinforced structures can be seen in Table 2.

According to the preceding table, the mass participation value of diversity has met the requirements of SNI 1726-2019, as the effective mass participation factor for UX and UY is at least 90%.

4.1.2 Fundamental period analysis results

The examination of the structure's dynamic characteristics is derived from the tabular findings of the modal analysis. This examination of capital will consider the fundamental natural vibration time. The building must meet the fundamental natural vibration time standards, which stipulate that the value must be less than the Cu coefficient and the fundamental approach period (Ta). In this study, capital analysis employs eigenvalue analysis using the SAP2000-integrated Ritz Vector. After the building model has been fully loaded, the load and its own weight must be considered as the building's mass, centered on the mass points, before the fundamental natural vibration time analysis can be performed. Modal analysis employs twelve modes. The SAP2000 calculation results are shown in Table 3.

According to the preceding table, the mass participation value of diversity has met the requirements of SNI 1726-2019, as the effective mass participation factor for UX and UY is at least 90%.

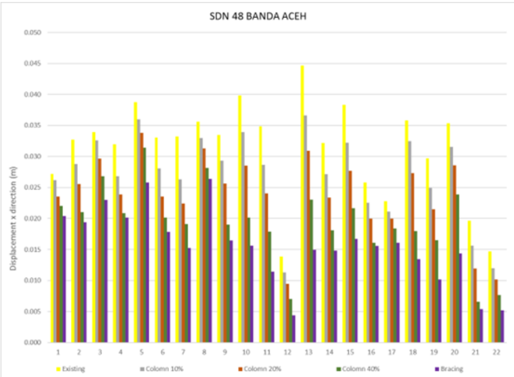
4.1.3 Base shear analysis results

According to Article 7.9.1 of SNI 1726-2019, the base shear force (Vt) must be greater than V, where V=Cs.W. Where Cs is the seismic response coefficient and W is the seismic weight of the structure. The effective seismic weight (W) may be determined with SAP2000 and Cs is 0.0703. Allowing Table 4 to display the seismic base shear force for reinforced concrete structures.

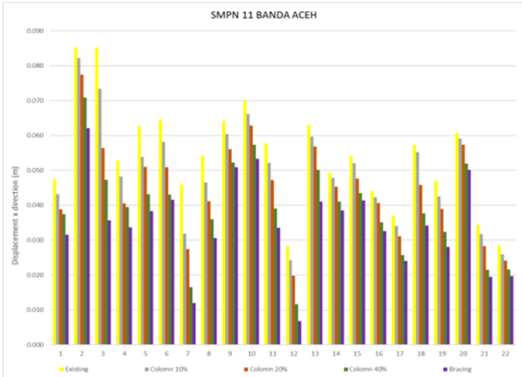
The seismic retrofitting models with X-bracing are used to maintain the building's stability owing to lateral forces and the structure's general stability. The X-bracing frame is a development of the Moment Resisting Frames (MRF) system and is a concentric brace. This concentrically braced structure has a high degree of stiffness and can sustain

Table 5 Base shear analysis results by using retrofitting X-bracing

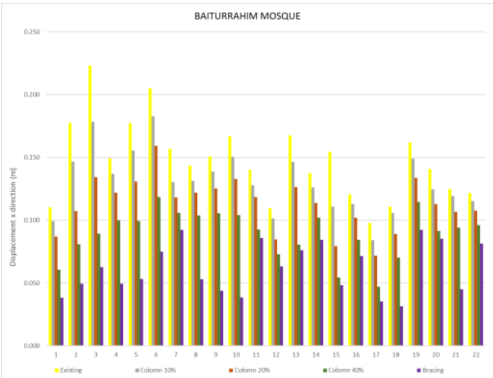
Buildings	V	Base Shear Vt		Description	
	Kgf	Vtx	Vty	Vt>V	
SDN 48 Banda Aceh	18486.859	27190.17	21132.23	Ok	Ok
		21328.87	27205.44	Ok	Ok
SMPN 11 Banda Aceh	148028.988	214680.97	151723.10	Ok	Ok
		149015.09	214680.97	Ok	Ok
Baiturrahim Mosque	55126.545	79947.99	69487.50	Ok	Ok
		71281.74	79947.99	Ok	Ok
Subulussalam Mosque	129479.595	191273.90	129526.07	Ok	Ok
		129740.62	188042.91	Ok	Ok



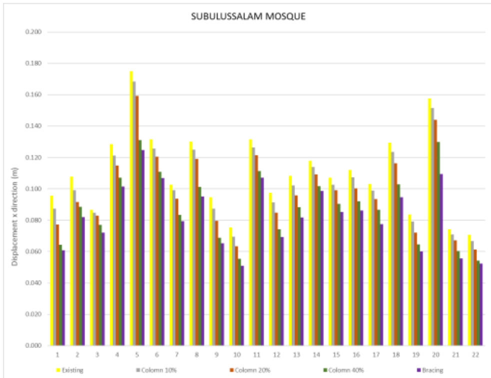
(a) SDN 48 Banda Aceh



(b) SMPN 11 Banda Aceh



(c) Baiturrahim Mosque



(d) Subulussalam Mosque

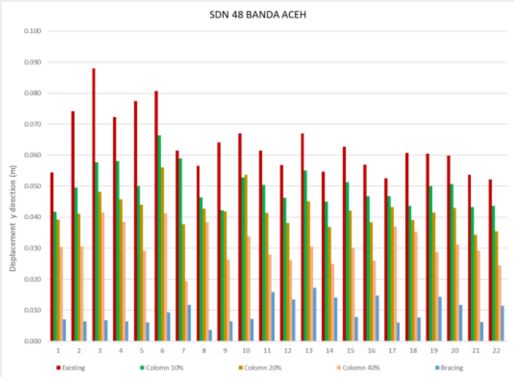
Fig 10. The results of the displacement analysis for the direction of the earthquake *x* in each building.

lateral forces. Because of the addition of bracings, the effective seismic weight (W) may be calculated to be dissimilar from that of the existing structure. Table 5 displays the seismic base shear force with retrofitting *X*-bracing since the base shear resulting from retrofitting *X*-bracing differs from the base shear of the current building.

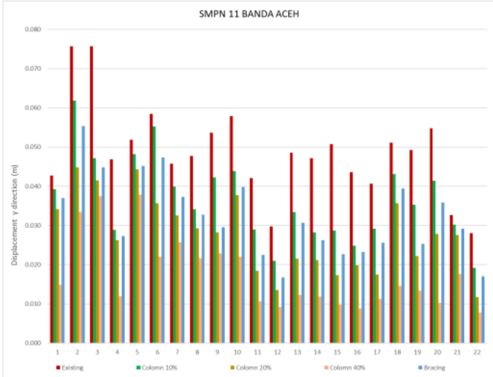
On the basis of the Table 4 and Table 5 foregoing, it is clear that the basic shear force complies with the requirements of SNI 1726:2019 under the condition that the basic shear force obtained from the spectrum response analysis is equal to 100 percent of the seismic base force calculated using the equivalent static method. In addition, Table 5 demonstrates that retrofitting *X*-bracings significantly increase the base shear value, while still meeting building code requirements. It is stated that concentric bracing will have an effect on the effective seismic weight of structures and have a substantial effect on the analysis of base shear on every building.

4.1.4 Displacement and drift ratio analysis results

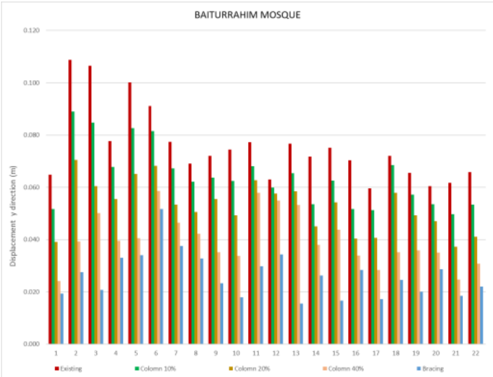
The output of SAP2000 for this analysis is the displacement. Displacement is one of the essential factors for determining the displacement caused by the operating load. A combination of calculated loads is carried out in order to examine the building's point of greatest displacement. For this study's investigation, 22 earthquakes were utilized to generate 22 displacement ratios. The displacement value is also converted into a drift ratio. The drift ratio is determined by comparing the building's displacement to its height per level. The results of the



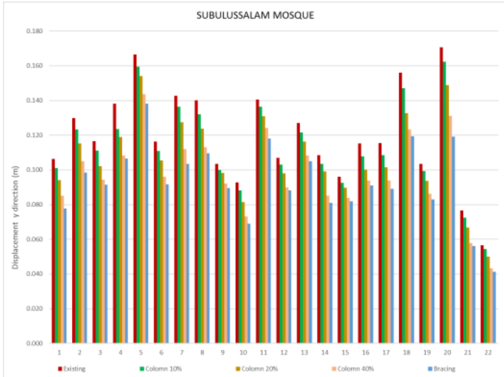
(a) SDN 48 Banda Aceh



(b) SMPN 11 Banda Aceh



(c) Baiturrahim Mosque



(d) Subulussalam Mosque

Fig. 11 The results of the displacement analysis for the direction of the earthquake *y* in each building

Table 6 Summary of displacement values of existing buildings

Buildings	Displacement *x* direction (m)		Displacement *y* direction	
	Max	Min	Max	Min
SDN 48 Banda Aceh	0.0447	0.0138	0.0880	0.0522
SMPN 11 Banda Aceh	0.0853	0.0283	0.0757	0.0281
Baiturrahim Mosque	0.2230	0.0980	0.1088	0.0596
Subulussalam Mosque	0.1750	0.0707	0.1706	0.0565

displacement analysis of the existing building have been utilized by Irfan *et al.* (2022) to assess the building's deformation using the Incremental Dynamic Analysis method and to design a Fragility Curve to anticipate the resulting damage. The fragility curves, also known as the vulnerability curves, are a method used to examine the anticipated seismic performance of structures. They reflect the chance of surpassing a damage limit state as a function of earthquake intensity. In addition, the Fig. 10 to Fig. 11 display the results of displacement for all earthquake data from time history analysis on many ground motions increment scales and for all retrofitting techniques.

4.1.5 Displacement of existing buildings

The findings of the displacement of the existing building indicate that the structure of the building deforms differently in response to the earthquake load. The 22 used ground movements exhibit different displacements. The following Table 6 provides a summary of the displacement analysis results for each building along the *x* and *y* axes.

The results of the table indicate that the building structure has varied *x*- and *y*-direction weaknesses. With a displacement value of 0.0880 m in the *y* direction and 0.0447 m in the *x* direction, the SDN 48 building is most vulnerable along the *y* axis. SMPN 11 and Baiturrahim Mosque structures show stronger *x*-direction susceptibility with displacements of 0.0853 m and 0.2230 m, respectively, whereas the *y*-direction values are 0.0757 m and 0.1017 m. In contrast to the other three public structures, the Subulussalam Mosque building has nearly identical vulnerability in the *x* and *y* directions, with values of 0.1750 m and 0.1706 m, respectively.

4.1.6 Displacement of buildings with column jacketing

According to the results of the column jacketing analysis, the building structure exhibits distinct deformations based on the proportion of column area that is widened as column jacketing. The following Table 7 provides a summary of the displacement analysis results for

Table 7 Summary of building displacement values with retrofitting column jacketing

Buildings	Displacement *x* direction (m)			Displacement *y* direction (m)		
	Column 10%	Column 20%	Column 40%	Column 10%	Column 20%	Column 40%
SDN 48 Banda Aceh	0.0366	0.0338	0.0314	0.0664	0.0561	0.0415
SMPN 11 Banda Aceh	0.0822	0.0774	0.0708	0.0618	0.0448	0.0379
Baiturrahim Mosque	0.1828	0.1593	0.1184	0.0890	0.0704	0.0586
Subulussalam Mosque	0.1684	0.1593	0.1311	0.1624	0.1540	0.1436

Table 8 Summary of building displacement values with retrofitting steel bracing

Buildings	Displacement *x* direction (m)		Displacement *y* direction (m)	
	Max	Min	Max	Min
SDN 48 Banda Aceh	0.0264	0.0044	0.0172	0.0037
SMPN 11 Banda Aceh	0.0621	0.0068	0.0553	0.0167
Baiturrahim Mosque	0.0924	0.0314	0.0517	0.0155
Subulussalam Mosque	0.1247	0.0510	0.1381	0.0413

Table 9 The percentage differences in displacement of existing and retrofitting structures

Building	*x* direction (%)				*y* direction (%)			
	Column 10%	Column 20%	Column 40%	Bracing	Column 10%	Column 20%	Column 40%	Bracing
SDN 48 Banda Aceh	18.0	24.4	29.7	40.9	24.5	36.2	52.8	80.4
SMPN 11 Banda Aceh	3.6	9.2	16.9	27.2	18.3	40.8	50.0	26.9
Baiturrahim Mosque	18.0	28.6	46.9	58.5	18.2	35.3	46.1	52.5
Subulussalam Mosque	3.8	9.0	25.1	28.7	4.8	9.7	15.8	19.1

Table 10 Summary of joint reactions with retrofitting X-bracings

Buildings	Item	Existing		Retrofitting X-bracing	
		Max (kg)	Min (kg)	Max (kg)	Min (kg)
SDN 48 Banda Aceh	FX	16514,62	-16262,64	214144,94	-218853,02
	FY	8344,92	-8108,89	158719,27	-132545,76
	FZ	46636,20	-8370,10	121893,96	-39192,22
SMPN 11 Banda Aceh	FX	101308,08	-101674,44	779087,91	-848183,39
	FY	104865,80	-99871,45	718320,78	-652572,72
	FZ	163874,85	-136302,40	283368,77	-289399,26
Baiturrahim Mosque	FX	9383,22	-9575,09	22453,11	-22817,28
	FY	15507,38	-15307,71	35414,13	-31980,06
	FZ	71054,24	-5942,32	100059,04	-7651,63
Subulussalam Mosque	FX	54284,93	-55554,54	79342,78	-78012,17
	FY	43806,46	-41377,04	67109,23	-69340,75
	FZ	297907,90	-21432,56	393223,96	-30041,62

each building along the *x* and *y* axes.

The results of the table indicate that the *x*- and *y*-direction weaknesses of the building structure are distinct. All building structures exhibit a decrease in displacement deformation as a result of each column expansion. This is because a structure's columns are better suited to handle a heavier load the broader they are. After simulating column jacketing for the SDN 48 building, the greatest risk remains in the *y* direction relative to the *x* direction. Moreover, the SMPN 11 and Baiturrahim Mosque structures are more susceptible to *x*-direction damage than *y*-direction damage. In contrast to the preceding three public buildings, the Subulussalam Mosque building is vulnerable in both the *x* and *y* directions.

4.1.7 Displacement of buildings with steel bracing

The findings of the column jacketing study indicate that the insertion of bracing alters the structural deformations of the building. The following Table 8 provides a summary of the displacement analysis results for each building along the *x* and *y* axes.

The results of the table reveal that the structure of the building has varying *x*- and *y*-direction vulnerabilities. It appears that every time a column is enlarged, all building structures experience a reduction in displacement deformation. The larger a structure's column's diameter, the higher its capacity to support a bigger load. After simulating column jacketing for the SDN 48 building, the *y* direction remains more susceptible than the *x* direction. The *x*-direction poses a greater threat than the *y*-direction to the SMPN 11 and Baiturrahim Mosque constructions. In contrast to the other three public buildings, the Subulussalam Mosque's susceptibility in the *x* and *y* directions is practically comparable.

The displacement results in Tables 7 and 8 indicate that the displacement of buildings with retrofitting has decreased significantly compared with existing structures. This output can be a further analysis to determine which retrofitting can be the effective method. The following Table 9 provides information about the percentage differences in retrofitted output compared with existing output.

4.1.8 Load on foundations

Constructing the foundation is the first step in any substantial building project. To ensure that the foundation can readily sustain all anticipated loads, it is essential not only to monitor the laying technique but also to calculate all potential impacts. The precise calculations take into account all aspects that could have even the smallest effect on the foundation. The following Table 10 provides the load on foundation by using concentric *X*-bracings.

The result of the table reveals that the value of load foundations for both existing and retrofitted buildings varies, but displays a similar pattern in which the value of the *z* direction or vertical direction exhibits a greater trend than the *x* and *y* directions. In addition, buildings with concentric bracing indicate a large rise in the value of load foundations. For the SDN 48 Banda Aceh and SMPN 11 structures, the *x* and *y* directions did not suffer a substantial increase, whereas the *z* direction did. In contrast to the two previously mentioned buildings, the Baiturrahim Mosque and Subulussalam Mosque buildings in the *x*, *y*, and *z* directions saw very tremendous growth. This is influenced by the building's shape, since the school buildings have the characteristics of a simple structure with minimal spacing between columns. In contrast, mosque structures have a more complex design with higher column diameters and wider column spacing than school buildings. Therefore, the calculation of load foundations is crucial, as calculations and their analysis must be performed while planning a construction project; otherwise, the repercussions of employing wrong numbers might be dreadful.

4.1.9 Cost estimation of retrofitting

In order to estimate the amount of retrofitting costs or planned reinforcing components for a structure, it is essential to be aware of the applicable standardized pricing provisions. Referring to the standards of the Indonesian Building Code, the first step in the cost of strengthening a structure is to estimate the building's asset value. The value of building assets is determined by multiplying the existing building area by the Highest Unit Cost to Construct a State Building. This provision refers to Regulation No. 45/PRT/M/2007 of the Minister of Public Works on Technical Guidelines for the Construction of State Buildings.

The estimated asset value of public buildings in Meuaraxa District is calculated by dividing the floor area of the existing building, the coefficient of the number of floors of the building, the coefficient of building function, and the City Government of Banda Aceh's Highest Unit Price for the Construction of a State Building in 2022. In the meantime, the cost of strengthening the structure is determined by multiplying the projected retrofitting volume by the unit cost of the work. The SAP2000 output values for each building were used to determine the projected retrofitting volume, which included the volume of concrete column jacketing and the weight of steel bracings. The unit price assessment is based on direct costs in accordance with the price guidelines outlined in Governor Regulation No. 65 of 2020. Tables 11 to 14 provide a summary of the calculation findings for retrofitting estimates for public buildings in the Meuraxa District for each retrofitting condition.

The results of the Table 11 indicate that the building's structure has a cost increase similarity of less than 0.5%. This retrofitting appears to be relatively economical. Especially Baiturrahim Mosque and Subulussalam Mosque have a value greater than 0.3%, with respective price increases of 0.39 and 0.34. This is owing to the mosque's asymmetrical structure and enormous circular column. Looking at the table in greater detail, the decrease in displacement is variable. It appears that the retrofitting with column jacketing expanded by 10% has a substantial effect on SDN 48, SMPN 11, and Baiturrahim Mosque, as the percentage of increased displacement is greater than 10% (excluding *x* direction for SMPN 11). For the Subulussalam Mosque, the percentage of decreased displacement in the *x* and *y* axes is nearly 5%.

Table 12 demonstrates that the structure of the building has a similarity trend of cost increase with the value of less than 1%. This retrofitting appears to be cost-effective, as does the 10% expansion of retrofitted column jacketing. Only school buildings had a value below 0.5 percent, with 0.35 percent for SDN 48 and 0.41 percent for SMPN 11. The table also indicates that the decrease in displacement exceeds 10%. In particular, three of the buildings have a value percentage greater than 20%. Only the Subulussalam Mosque has a valuation that has reduced by approximately 10%.

The building's structure has a similar tendency of a 20% cost rise with retrofitting, as seen by the data in the table above. The estimated cost of this retrofitting, however, appears to have risen significantly. The percentage value of retrofitting costs for school buildings is clearly less than 1.0 %. In addition, mosques have a greater cost increase pattern than schools, exceeding 1.5%. It is possible for it to be a cost-effective retrofitting option, however it is not when compared to the two retrofitting methods listed previously.

Table 11 Summary of cost estimations with column jacketing expanded 10%

Buildings	Total Asset Cost	Total Retrofitting Cost	Cost Increase	Decrease in Displacement (%)	
	(IDR)	(IDR)	(%)	*x*	*y*
SDN 48 Banda Aceh	2.809.856.000	4.738.986	0,17	13,37	20,75
SMPN 11 Banda aceh	18.473.000.000	36.468.043	0,20	8,86	25,25
Baiturrahim Mosque	5.067.738.000	19.609.522	0,39	10,98	15,11
Subulussalam Mosque	8.602.565.400	28.927.171	0,34	5,03	4,92

Table 12 Summary of cost estimations with column jacketing expanded 20%

Buildings	Total Asset Cost	Total Retrofitting Cost	Cost Increase	Decrease in Displacement (%)	
	(IDR)	(IDR)	(%)	*x*	*y*
SDN 48 Banda Aceh	2.809.856.000	9.929.304	0,35	24,36	32,89
SMPN 11 Banda aceh	18.473.000.000	76.409.234	0,41	17,70	43,64
Baiturrahim Mosque	5.067.738.000	41.086.618	0,81	22,61	29,80
Subulussalam Mosque	8.602.565.400	60.609.310	0,70	10,77	10,51

Table 13 Summary of cost estimations with column jacketing expanded 40%

Buildings	Total Asset Cost	Total Retrofitting Cost	Cost Increase	Decrease in Displacement (%)	
	(IDR)	(IDR)	(%)	*x*	*y*
SDN 48 Banda Aceh	2.809.856.000	21.663.936	0,77	22,61	29,80
SMPN 11 Banda aceh	18.473.000.000	166.711.056	0,90	29,36	64,71
Baiturrahim Mosque	5.067.738.000	89.643.530	1,77	38,40	46,46
Subulussalam Mosque	8.602.565.400	132.238.497	1,54	19,84	18,47

Table 14 Summary of cost estimations with retrofitting X-bracings

Buildings	Total Asset Cost	Total Retrofitting Cost	Cost Increase	Decrease in Displacement (%)	
	(IDR)	(IDR)	(%)	*x*	*y*
SDN 48 Banda Aceh	2.809.856.000	147.735.200	5,26	50,55	84,40
SMPN 11 Banda aceh	18.473.000.000	705.283.000	3,82	37,43	33,99
Baiturrahim Mosque	5.067.738.000	229.791.600	4,53	57,30	64,70
Subulussalam Mosque	8.602.565.400	446.945.000	5,20	25,06	22,00

Furthermore, the percentage of decreased displacement has presented a range of trends and has values greater than 18%, with one building having a value of about 50%. The only structure whose value has decreased by less than 20% is the Subulussalam Mosque.

With column jacketing, the results of retrofitting with *X*-bracings are unique and distinct. Table 14 clearly shows that the structure of the building has a cost increase between 3.5 and 5.5 percent. As opposed to the column jacketing method, this retrofitting appears to be quite costly. This is due to steel bracing is extremely expensive in Banda Aceh. SMPN 11 has the smallest cost rise at 3.82%, while SDN 48 has the most at 5.26%. The cost increase for Baiturrahim Mosque and Subulussalam Mosque is 4.53 percent and 5.20 percent, respectively. Comparing column jacketing retrofitting to the percentage of decreased displacement in the table, there is a massive increase. All structures have a percentage greater than 20%, notably SDN 48 and Baiturrahim Mosque above 50%. SDN 48 has the highest value for *y* direction at 84.40 percent, while Subulussalam Mosque has the lowest at 22 percent. However, if the economic component is essential, the proportion of cost estimation for retrofitting should be considered.

5. Conclusions

The Banda Aceh is susceptible to its earthquake risk. According to an assessment of the region's public buildings, they have one of the most seismically vulnerable building types. Therefore, a solution is required to enhance their seismic response in the event of an earthquake. The results indicate that this strategy is reliable and has successfully attained the desired objective. The goal of this study is to determine how to more effectively and economically seismically upgrade public buildings in the Meuraxa district in order to decrease their seismic sensitivity. In order to determine whether existing structures' seismic susceptibility may be decreased, this article studied and contrasted two different seismic retrofitting techniques. The investigation was carried out in mosques and schools in Banda Aceh.

Only retrofitting elements in the building's most vulnerable direction can produce a greater efficiency than retrofitting elements in both directions, according to linear time history analysis. The performance of the opposite direction was unaffected by the addition of bracings, jackets, or single braces in only one direction. The building of walls, on the other hand, had positive effects on both sides. It has also been demonstrated that not all columns or bays in a structure need to have retrofitting features. The best places to apply retrofitting elements must be chosen in order to produce a profitable improvement.

According to an analysis of the findings, the building has to be reinforced seismically to protect the mosques and schools in the case of an earthquake. Additionally, it has been demonstrated that the structure is hazardous under seismic loads in the *X*- or even *Y*-direction without alteration, making it susceptible to major earthquake damage. The investigation in this case has demonstrated that the suggested seismic retrofitting may make the structure safe. Analysis has shown that steel jacketing is necessary to address the problem of the short column, which is a seismic weak point. Additionally, the top stories' column distortion is lessened. In this case, the majority of the plastic hinges are concentrated in the first-floor columns' residual strength area.

The findings also show that the steel *X*-bracing and *Y*-bracing types offer the most improvements in seismic performance. The top-floor columns, which in the original RC structure display more deformation, perform better during earthquakes thanks to the *X*- and *Y*-direction bracings. Through this retrofitting procedure, the frames' strength and rigidity are increased, and ground-floor soft-storey impacts are avoided. In comparison to its equivalent, the bracings type with a steel WF 250.125.9.6 section minimizes displacements more.

Because they enhance the seismic behavior of the structure without interfering with the operation of public buildings, bracings are the most efficient retrofitting technique. When steel jackets of various thicknesses are retrofitted to the framework, the capacity barely rises. Many of them have high proportions of the damage limit state, which shows that the building is susceptible to seismic forces. Retrofitting strategies utilizing bracings, however, produce a noticeable improvement. It has been established as a result that locating the seismically vulnerable areas where seismic retrofitting components can be introduced is more effective than obtaining a successful building modification. The most effective method in this regard has turned out to be the retrofitting strategy using the *X*- and *Y*-direction bracings, which are the weakest in the building. These retrofitting ideas greatly increase the seismic performance of the original structure while without interfering with its use.

In addition, the correct values of load on foundations will allow user to determine the most appropriate and secure location to build a structure. If the calculations are accurate, it is simple to prevent probable deformation of the walls or the foundation and, in turn, the structures. If the calculations are performed incorrectly or not at all, building and foundation deformations such as skew, bending, subsidence, buckle, roll, shear, and horizontal displacement may occur.

Moreover, the results of calculating estimated costs for retrofitting reveal that the estimated costs for each planned retrofitting vary. In order to determine the effectiveness of a retrofitting procedure, it is essential to consider both the economic and safety benefits, such as a large reduction in displacement.

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