

Direct Application of Experimental Results Using External GFRP Reinforcement on Spiral Concrete Columns Applied in the Strength Analysis of Multi-Storey Grandstand Buildings for Strong Earthquake-Prone Areas in Indonesia

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Abstract Eastern Indonesia, West Sulawesi Province the city of Mamuju is a region that is very prone to earthquakes. The earthquake in 2021 caused the Governor's Office Building to collapse completely. This condition caused the building structural systems in the city of Mamuju to suffer extensive damage and total collapse, particularly in the building columns. With this incident, building or house structures are provided with solutions to anticipate structural damage during a strong earthquake so that the structures can withstand and protect their occupants from the risk of earthquake hazards. One of the solutions in this article is to provide an additional external GFRP reinforcement placed on reinforced concrete columns aimed at increasing lateral stress. The use of external GFRP reinforcement is highly relevant in contemporary conditions with the advancement of material technology in concrete, namely Glass Fiber Reinforced Polymer (GFRP). The results of the tests on the circular concrete columns conducted in the structural laboratory using GFRP material as external reinforcement showed a very significant impact on axial strength. Thus, in the direct

application to the 5-story grandstand building using external GFRP reinforcement on the reinforced concrete columns, it is shown that there are no overstressed structural element components.

Keywords Concrete Columns, External GFRP, Reinforcement, Building Analysis

1. Introduction

Eastern Indonesia, such as North Sulawesi, West Sulawesi, and Central Sulawesi, is the region with a very high level of earthquake risk. This can be seen with various earthquake incidents in recent years that have struck several areas in Eastern Indonesia. This condition causes the structural systems that have been built in this area, particularly the building column elements which are compression elements, to experience failure and collapse. Therefore, when planning the column elements in

buildings, one must be more vigilant and meticulous in analysis and fieldwork. Although, in theory, it is said that during a strong earthquake, certain selected structural elements of a building are allowed to undergo plastic deformation as a means of dissipating the seismic energy received by the structure.

However, the structure is expected not to collapse. In order for the building structure not to collapse, the structural elements, especially those with the potential to form plastic hinges, must be provided with sufficient reinforcement detailing to make the structure ductile. A structural element of a building that has the potential to experience plastic hinges is the column area, so to this day, the strength behavior of columns is still being researched. In various earthquake incidents in the region, the strong occurrences show that the buildings are very fragile, and many buildings suffer severe damage. Buildings without earthquake design show a decrease in quality and behave in a non-ductile manner. Therefore, it is very important to conduct an accurate analysis by considering the effects of the earthquake that occurs [1]. Earthquake activity has significantly increased. Thus, the proportional increase in high-rise building construction has heightened the relevance of progressive building analysis in preventing collapses. Buildings analyzed for earthquake resistance contribute to the development of more resilient and robust design practices, which ultimately ensure the safety and structural integrity of the building during extreme events such as earthquakes [2]. In building structures with all regular configurations, it is often not feasible due to irregular plot dimensions. Structures with irregular configurations, both horizontally and vertically, are more vulnerable to earthquake and wind forces, leading to structural failures and casualties due to building collapses. Therefore, buildings are designed to be regular and take into account the provision of shear walls to provide a good response in resisting lateral forces such as earthquakes [3].

Recently, research has been conducted on the strengthening and repair of concrete structural elements using composite fiber materials, namely Fiber Reinforced Polymer (FRP). These strengthening and repair actions are the right solution to maintain the strength and long-term use of the structure. This condition requires the reinforcement and repair of structural elements due to environmental changes, sudden load additions, natural disasters, corrosion of structural elements, and the lack of continuous maintenance. The use of FRP in structural elements can increase large axial strains, showing superior deformability and ductility performance [4]. Even in the concept of earthquake safety in buildings, it is also necessary to analyze structures that pay attention to earthquake codes related to the concept of structural dynamic analysis based on the stresses and forces that can be accepted by the structure [5].

Many studies have been conducted on structural reinforcement to withstand bending and shear using FRP materials. Research leads to a better understanding and the

establishment of guidelines in the design and work using FRP materials on building structural elements [6]. Studies have been conducted on cylindrical column elements using CFRP, showing an increase in strength and better strain, with greater energy absorption compared to those without external CFRP reinforcement [7]. Experimental investigation on beams to observe the performance of beams reinforced with external CFRP reinforcement materials shows good performance [8]. FRP is a composite polymer fiber that has been used in advanced concrete due to its advantages over traditional steel reinforcement. FRP fiber material is a material that has a high strength capacity and corrosion resistance and can be combined with adhesives and anchors that function to contribute strength to structural elements such as reinforced concrete columns. Reinforced concrete columns with FRP external reinforcement can add strength and strong resistance to bending, shear, torsion and even external impacts and explosions. The increase in strength that occurs in reinforced concrete columns or beams reinforced with FRP composite fibers. FRP reinforcement in its strength is available in concrete columns and concrete beams are controlled by the fiber material, configuration and reinforcement strategy used [9].

Renovating to strengthen the structure on structural elements using GFRP material can increase compressive capacity [10]. Researchers have conducted studies to convey concepts. This includes research into column behavior for cylindrical columns with rectangular cross-section models, externally reinforced with CFRP composite fibers under eccentric loading, which can increase axial and flexural stiffness and improve the performance of concrete columns that are given longitudinal reinforcement [11]. The researcher presented the results of his research about structural investigations on steel pipes and their concrete contents (CFST) with the application of FRP strength as external reinforcement, which has a higher load capacity. It is said that the structural elements of the building can have their cross-sections reduced, with very good seismic resistance properties, and the building structure is even fire-resistant [12]. Then, the plate structure elements have also been reinforced using CFRP, showing that the reinforcement system provided is very effective in increasing the shows that the effectiveness of the reinforcement produced in increasing the flexural strength of two-way reinforced slabs [13]. Structural planning and analysis of a building are generally carried out with structural software, including the ETABS structural software. In the analysis, it includes a comparison of shear force variations, bending moment values, and reinforcement details obtained using the ETABS structural software [14]. Multi-story buildings can be analyzed using 3D structural modeling through ETABS structural software by fulfilling all applicable regulations in Indonesia including building and non-building structure guidelines and Indonesian National Standard (SNI) 1726:2012 regulations. The planning and analysis system

in high-rise building structures is designed with a portal frame model. The main structural elements are columns and beams made from conventional concrete. Beams transversely bear the load by transmitting this load to the column elements. The foundation receives the load transmitted from the columns axial load from the beam elements. For the planning of multi-story buildings in strong earthquake regions, the analysis is conducted using the special moment-resisting frame (SMRF) structural system with the concept of strong column weak beam [15]. Evaluation of the seismic response of shear walls is also very influential in the design of earthquake-resistant structural buildings in maintaining the stability and resistance of the structure to lateral loading. Structural forms including an asymmetric building opening model with the influence of earthquake loads are analyzed with ETABS structural software effectiveness that occurs in the vertical opening model of the asymmetrical building [16].

In the development of research, the application of ETABS structural software in solving the problem of dynamic behavior of structures in high-rise buildings is very important. Various cases can be carried out with different structural analysis and loading combinations according to the model and design needs. ETABS software is a typing software used for high-rise building planning. This software can solve various cases including calculating shear forces and bending moments that occur in a building from a combination of loads. In this software, the building can be designed by examining several parameters set by the standards applicable in each country and can provide cross-reference regulations between countries. Thus, safety in analysis such as safety in column and beam structural elements can be checked in accordance with the regulations that have been established to be the main source of analysis and planning. The use of ETABS software for the purpose of an analysis to determine a stability and even strength to tall buildings allows direct application to building structural elements such as concrete columns that are given the addition of GFRP reinforcement externally, ensuring the usability aspects of this developing GFRP material, which is used by many countries around the world. The use of external reinforcement can be applied to multi-story grandstand buildings to accommodate various human activities. Therefore, to realize this aspect of utility from the external GFRP reinforcement, a global analysis of the multi-story structure is conducted using the ETABS structural software [17].

One of the methods used to achieve satisfactory behavior in the column is by installing external GFRP reinforcement as a strengthening reinforcement to resist lateral forces. The use of reinforcement in columns that has been widely employed so far is the use of steel reinforcement with conventional methods without the use of external GFRP reinforcement.

The use of conventional reinforcing steel in concrete columns has the advantage of being easily available and affordable and the implementation of the reinforcement

does not require special handling. However, the drawback is that it cannot provide maximum strength if the concrete column element is hit by a strong earthquake. The use of GFRP fiber material as external reinforcement in reinforced concrete columns has the potential to increase the dead load of the structure, thereby reducing its strength. Confinement with this conventional model, according to experts, is considered not yet capable of providing sufficient ductility, resulting in many cases of column failure in construction. An example of the use of reinforcement steel in Mamuju City, West Sulawesi as a confinement that is unable to maintain the structural stability of the column during a strong earthquake is shown in Figure 1 and Figure 2.



Figure 1. The West Sulawesi Governor's Office Collapsed During the 2021 Earthquake



Figure 2. Severe Damage to the Structural Element of the West Sulawesi Governor Collapsed during the 2021 Earthquake

2. Methodology

Based on the research objectives that have been stated, an analytical and experimental study was conducted. The analytical study began with inventorying the progress or recent information on research regarding the use of Glass Fiber Reinforced Polymer (GFRP) as reinforcement in concrete columns. The stress-strain relationship behavior of GFRP reinforcement, the failure mechanism in concrete columns, especially under uniaxial load, behavior of stress-strain relationship of reinforcement using GFRP material, and failure mechanism in concrete columns, especially under uniaxial load are to find out the strength enhancement result of GFRP fiber material. The next analysis study is to examine the models of external reinforcement of GFRP in concrete columns that are

already present in the literature, followed by the evaluation of some design parameters that affect the strength behavior of concrete columns provided with GFRP external reinforcement.

Experimental studies on concrete columns were conducted to examine reinforced concrete columns with external GFRP reinforcement. Several parameters are evaluated on the strength behavior of a column in concrete. The correlation between the models of GFRP reinforcement usage in concrete columns and the test results is examined to determine the sensitivity or characteristics of each model.

Next, activities were conducted in the laboratory, including the planning, fabrication, and testing of the round column test specimens. The test specimens are designed to be provided with external GFRP reinforcement on concrete columns with various spacing variations of GFRP usage. The testing was conducted with a concentric axial load with parameters that will be varied according to the research objectives, including the shape and spacing of GFRP reinforcement usage. The expected results from the testing with concentric axial load are an increase in strength and strain behavior, as well as the column failure model with various spacing variations of Glass Fiber Reinforced Polymer (GFRP). The GFRP material is shown in Figure 3 and the test setup with concentric axial load is shown in Figure 4.

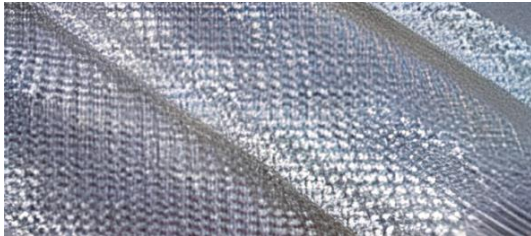


Figure 3. GFRP reinforcement material

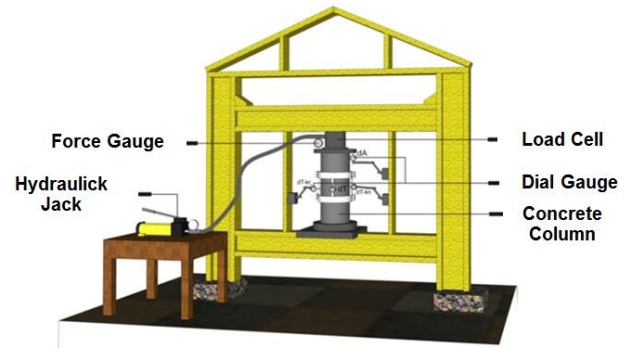


Figure 4. Test Set-up for concentric column specimen testing

Glass Fiber Reinforced Polymer (GFRP) is a glass fiber material bonded with a polymer matrix that has the advantage of high tensile strength and light weight and can be formed easily. The GFRP material used is GFRP Tyfo SHE-25A Composite with characteristics shown in Table 1, Composite Gross Laminate Properties shown in Table 2, and Epoxy Material Properties shown in Table 3.

Table 1. Typical Dry GFRP Properties

TYPICAL DRY GFRP PROPERTIES	
Tensile Strength	3.24 GPa
Tensile Modulus	72.4 Gpa
Ultimate Elongation	4.50%
Density	2.55 g/cm ³
Weight per sq. yd.	505 g/m ²

For testing on several concrete column specimens using GFRP material, concentric axial loading performed with parameters varied according to the research objectives. The test model is shown in Figure 4.

Table 2. Composite Gross Laminate Properties

PROPERTY	ASTM METHOD	TYPICAL TEST VALUE	DESIGN VALUE
Ultimate tensile strength in primary fiber direction	D-3039	521 Mpa	417 Mpa
Elongation at break	D-3039	2.00%	1.76%
Tensile Modulus	D-3039	26.1 Gpa	20.9 Gpa
Ultimate tensile strength 90 degrees to primary fiber	D-3039	25.8 Mpa	20.7 Mpa

Table 3. Epoxy Material Properties

PROPERTY	ASTM METHOD	TYPICAL TEST VALUE
Tg 140 ⁰ F (60 ⁰ C) Post Cure (24 hours)	ASTM D-4065	180 ⁰ F (82 ⁰ C)
Tensile Strength	ASTM D-638 Type 1	72.4 Mpa
Tensile Modulus	ASTM D-638 Type 1	3.18 Gpa
Elongation Percent	ASTM D-638 Type 1	5.00%
Flexural Strength	ASTM D-790	123.4 Mpa
Flexural Modulus	ASTM D-790	3.12 Gpa

Based on the experimental results in the laboratory and analysis of conventional internally reinforced concrete columns reinforced with GFRP reinforcement on the concrete surface, it was then implemented into a multi-story building, specifically a 5-story grandstand building. The purpose of this implementation is to determine the dynamic characteristics that occur due to seismic loads and to globally check the structure for stability and strength in reinforced concrete columns with external GFRP reinforcement. This direct implementation can provide accurate information about the benefits of using GFRP reinforcement in multi-story buildings applied to reinforced concrete columns.

3. Results and Discussions

3.1. Structural Reinforcement

Structural reinforcement generally aims to increase the strength of structural elements so that they can withstand lateral loads as planned. Structural reinforcement is carried out using several methods. One of the structural reinforcement methods that can be employed is wrapping with GFRP reinforcement made of lightweight composite material.

3.2. Implementation of Structure

Preparation and implementation of the laboratory are carried out with:

a. Concrete surface preparation

The concrete surface that will be provided with GFRP external reinforcement must be ensured to be strong and sturdy, free from any cavities or weak spots, and clean from dust and other dirt to achieve a good bond so that the GFRP reinforcement material and the reinforced concrete column become a single unit.

b. Mixture comparison

Binder additives and mixing ratios of ingredients in concrete should be stronger as recommended by the manufacturer.

c. Pot life

It is the time during mixing for the GFRP reinforcement material to set properly in the concrete. If the time is not right in the installation, the GFRP fiber material can not be used. After completion of the implementation, quality control is considered for the adhesion of GFRP reinforcement material with concrete.

3.3. Application of Epoxy Resin

Epoxy resin is a solution used to bond GFRP

reinforcement materials to concrete columns or objects that need to be strengthened. The epoxy resin mixture consists of solid and liquid materials that dissolve into each other. The mixture with epoxy resin in concrete columns is used to achieve specific performance with the desired properties.

Epoxy resin is cured by adding anhydride or amine hardeners. Each hardener produces a different solution profile and desired properties for the final product. The drying speed can be controlled through the proper selection of the hardener to meet the process requirements.

3.4. Test Specimens and Testing

The test specimen used is a reinforced concrete spiral measuring 300 x 666 mm with 6D10 mm longitudinal reinforcement and Ø10 for circular stirrups as shown in Figure 5. The number of longitudinal reinforcements is determined by considering the capacity of the testing equipment to be used with circular stirrups spaced at $d/2$, where d is obtained by taking a clear concrete cover of 20 mm. The length of the overlapping stirrups follows the provisions in the Indonesian National Standard (SNI) 2002.



Figure 5. Configuration of concrete column reinforcement

The casting of test specimens is carried out in stages, with every 3 test specimens, considering the capacity of the mixing equipment. To obtain a consistent concrete mix, especially regarding the aggregate gradation, the aggregate diameter content is adjusted to be the same for each mixing. The curing of the test specimens is carried out after the molds are removed as shown in Figure 6. The curing was done by covering the specimens with wet gunny sacks and wrapping them with plastic. After the curing period, the specimens were stored in a safe place under room conditions until the installation of GFRP reinforcement material was ready at 28 days. After all concrete column specimens were ready for use, the concrete column specimens were leveled properly as shown in Figure 7 and the concrete column with GFRP material was wrapped on the surface of the concrete column as shown in Figure 8.



Figure 6. Release of molds and concrete quality testing



Figure 8. The process of wrapping the full GFRP layer



Figure 7. Leveling the test specimen for the installation of GFRP material

3.5. Model of Test Object Collapse

Each specimen tested exhibited its failure model when the test reached maximum load. The collapse model that occurred was observed during the testing process. The collapse model is shown in Table 4.

Table 4. Model of test object collapse

No	Specimen Code	Length Connection(mm)	Collapse Model
1	PCC-01	-	splitting
2	PCC-02	-	splitting
3	PCC-03	-	splitting
4	RCC-01	-	Spalling concrete cover
5	RCC-02	-	Spalling concrete cover
6	RCC-03	-	Spalling concrete cover
7	PCCL-01	12	GFRP came off
8	PCCL-02	12	GFRP came off
9	PCCL-03	12	GFRP came off
10	PCCL-04	12	GFRP came off
11	PCCL-05	12	GFRP came off
12	PCCL-06	12	GFRP came off
13	PCCL-07	12	GFRP rupture failure
14	PCCL-08	12	GFRP rupture failure
15	PCCL-09	12	GFRP rupture failure
16	RCCL-01	16	Diagonal cracking
17	RCCL-02	16	Diagonal cracking
18	RCCL-03	16	Diagonal cracking
19	RCCL-04	16	Diagonal cracking
20	RCCL-05	16	Diagonal cracking
21	RCCL-06	16	Diagonal cracking
22	RCCL-07	16	Diagonal cracking
23	RCCL-08	16	Diagonal cracking
24	RCCL-09	16	Diagonal cracking

The failure of the specimen in the plain concrete column without external GFRP reinforcement began with the occurrence of fine cracks on the surface of the test object, and the cracks widened as the load was increased until reaching the peak load. The cracking pattern that occurred was shown to be very rapid. The collapse model of the GFRP specimen without external reinforcement (PCC type) is categorized as splitting failure, where the crack pattern is parallel to the longitudinal axis of the test specimen.

The failure of the concrete column test specimen with internal reinforcement without external GFRP reinforcement (type RCC) is marked by the spalling of the concrete cover when the load approaches the peak load, and after surpassing the peak load, the test specimen (type RCC) is still able to provide significant strain until local buckling occurs in the longitudinal reinforcement. The test specimen (type PCCL) with the addition of one layer of external GFRP reinforcement without conventional longitudinal steel reinforcement, failure occurs in the concrete column after the external GFRP reinforcement experiences failure or begins to rupture. The failure of the external GFRP reinforcement layer is indicated by shear failure at the joint and rupture outside the joint. The external GFRP reinforcement installed with a 12 mm joint experienced shear failure at the joint, whereas the failure of the external GFRP reinforcement installed with a 16 mm joint on the concrete column (RCCL type), when tested to the peak point, was shown at the diagonal crack position. This indicates that the external GFRP reinforcement functions on the concrete surface, thus not showing any significant failure.

3.6. Stress-Strain Relationship

The stress-strain diagrams for all test specimens of plain concrete columns (PCC type), concrete columns with steel reinforcement (RCC type), plain concrete columns with external GFRP reinforcement (PCCL type), and reinforced concrete columns with external GFRP reinforcement (RCCL type) are plotted together as shown in Figure 9.

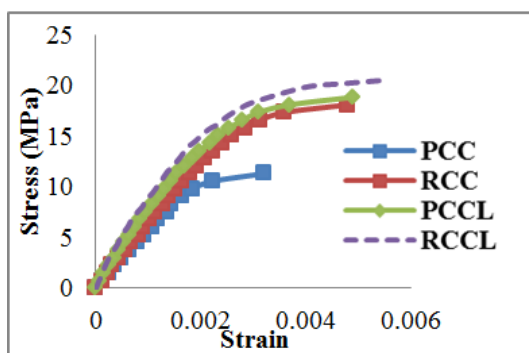


Figure 9. The relationship between average stress and strain for each test specimen

Figure 9 shows that the concrete column (PCC type) has

a very low maximum axial force due to the absence of reinforcement steel, while the concrete column (RCC type) with the use of reinforcement steel has an increasing axial force compared to the plain concrete column (PCC type). In the plain concrete column (type PCCL) that uses external GFRP reinforcement on its surface, the strength is shown to increase as seen from the strain-stress image that occurs. The external GFRP reinforcement layer has a stronger strength compared to the concrete column (RCC type) that uses conventional steel reinforcement. This is illustrated by the strain that occurs. Among all the specimens, the reinforced concrete column type RCCL using external GFRP has the highest stress, due to the reinforcing steel construction and the GFRP external reinforcement layer applied to the reinforced concrete column. This fact is shown in Figure 9, which indicates the stress-strain that occurs where the ascending branch increases before the concrete column collapses. The illustration shows that internal cracks undergo changes due to the applied load, the curve still represents an ascending line. However, with the increasing load, the internal cracks increase and there is also merging between one crack and another. This fact is observed from the nonlinear behavior of the ascending branch curve. The effect of using external GFRP reinforcement will take place after a volume change that occurs in the concrete. The ductility level of the test specimen can be seen from the end of the ascending branch of the curve. The flatter this section is, the more ductile its failure is. From Figure 9, it can be seen that the addition of an external GFRP reinforcement layer results in a longer ascending branch curve compared to concrete columns (PCC type) and (RCC type) that do not use external GFRP reinforcement, which have a flatter curve and more ductile failure. This shows that the use of external GFRP reinforcement on reinforced concrete columns can increase strength as demonstrated in the strain-stress graph shown in Figure 9 above.

3.7. Maximum Axial Load Capacity

In Figure 10, the results of the maximum axial load capacity obtained during laboratory testing on each test specimen are shown. Several types of test specimens were conducted, including plain concrete columns (type PCC), reinforced concrete columns (type RCC), plain concrete columns with external GFRP reinforcement on the concrete surface (type PCCL), and reinforced concrete columns with external GFRP reinforcement (type RCCL). The specimen is the maximum forces that can be accepted before failure. Table 5 shows the results of the average maximum force of a test specimen, namely the test specimen (PCC type), the test specimen (RCC type), the test specimen (PCCL type) with external GFRP reinforcement, and the test specimen (RCCL type) with external GFRP reinforcement. The axial load capacity achieved on average for the test specimens can be seen in Table 5.

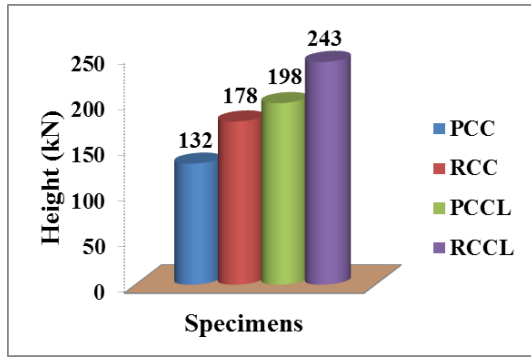


Figure 10. Axial load capacity of each type of test specimen

Table 5. Axial load capacity of each type of test specimen

Specimen Code	Axial Load Capacity (kN)	Average Axial Load Capacity
PCC-01	135	132
PCC-02	120	
PCC-03	140	
RCC-01	185	178
RCC-02	180	
RCC-03	170	
PCCL-01	210	198
PCCL-02	195	
PCCL-03	190	
RCCL-01	240	243
RCCL-02	255	
RCCL-03	235	

The results of the tests on the circular concrete columns conducted in the structural laboratory using GFRP material as external reinforcement showed a very significant impact on axial strength. Previously, tests were conducted on circular concrete columns without conventional reinforcement and without external GFRP reinforcement, showing that the axial strength reached only 132 kN. Meanwhile, circular concrete columns with internal conventional reinforcement, but without external GFRP reinforcement on the surface of the concrete columns, showed an axial strength of 178 kN. This experiences an increase in axial strength due to the provision of internal conventional reinforcement. Then, on the round concrete column without internal conventional reinforcement, but with external GFRP reinforcement on the surface of the concrete column, the result shows an axial strength of 198 kN. Meanwhile, the axial strength observed in the RCCL type specimen, which is the core of the research, significantly increased when the circular concrete column with conventional internal reinforcement was provided with external GFRP reinforcement on the surface of the concrete column, showing a maximum axial strength of 243 kN as shown in Figure 10. The increase in strength

from plain concrete columns without internal conventional reinforcement (type PCC) to plain concrete columns without internal conventional reinforcement but with external GFRP reinforcement on the surface of the concrete columns (type RCC) is 34.848%. Meanwhile, the increase in strength observed in the specimen of conventional internally reinforced concrete columns with external GFRP reinforcement (type RCCL) compared to the strength of the specimen of conventional internally reinforced concrete columns without external GFRP reinforcement on the surface of the concrete column (type RCC) resulted in a significant increase of 36.517%. An illustration is that the use of GFRP material as an addition of external reinforcement in concrete columns can experience an increase and even a much greater increase if the concrete column is given an additional GFRP layer and the test specimens reviewed are larger and higher. In future research, it will be relevant in regional conditions, especially in Indonesia where earthquakes often occur, and where concrete columns are sensitive to be strengthened because they are the main support for building structures.

3.8. Direct Application at the Grandstand Building

The use of external GFRP reinforcement in multi-story building applications is highly needed considering the material's ready availability, its lightweight, ease of application, high compressive strength, and good durability against corrosion. The strengthening of building structures on concrete column elements has been applied in several countries such as the United States, Japan, Canada, and Germany, and even has regulations governing the application of GFRP reinforcement materials.

Specifically, in Indonesia, there are regulations related to the use of GFRP reinforcement materials on building structure elements, which are included in the Indonesian National Standard (SNI) 8970:2021.

Therefore, in this additional research, after conducting experimental tests in the laboratory related to the use of external GFRP reinforcement on reinforced concrete columns, the discussion continues with a direct application on a 5-story grandstand building to determine the strength aspects of the multi-story building applied in strong earthquake-prone areas in Indonesia, known in the Indonesian National Standard (SNI) as earthquake zone IV. In this application, through the ETABS structural program, information about the dynamic characteristics of the structure and a global structural check to understand the stability aspects of the structure are provided.

For direct application on the grandstand building, a structural plan and a structural model of the 5-story building with external GFRP reinforcement on reinforced concrete columns were created using the ETABS structural software. The building model structure is designed with reference to the Indonesian National Standards (SNI) 2847:2019 and SNI 8970:2021.

a. Building Data Model

The building model in the application of external GFRP reinforcement on reinforced concrete columns is a 5-story grandstand building model with a dimensions of 80 m x 43.35 m. The building is planned in an area with a high earthquake risk, specifically in the city of Mamuju, West Sulawesi, Eastern Indonesia. The planned concrete material has a compressive strength of 33.2 MPa, and the steel reinforcement material is planned to use ribbed steel bars with a yield strength of 400 MPa. In this analysis,

several loading combinations are provided, including seismic loading in accordance with SNI regulations, to determine the strength results of the external GFRP reinforcement applied to reinforced concrete columns in strong seismic zones. Detailing calculations will be carried out after the analysis results that meet the requirements. Structural modeling is carried out using the ETABS program. The modeling can be seen in the following in Figures 11, 12, 13, and Figure 14. The floor plan of the Roof is shown in Figure 15 and the three-dimensional modeling is shown in Figure 16.

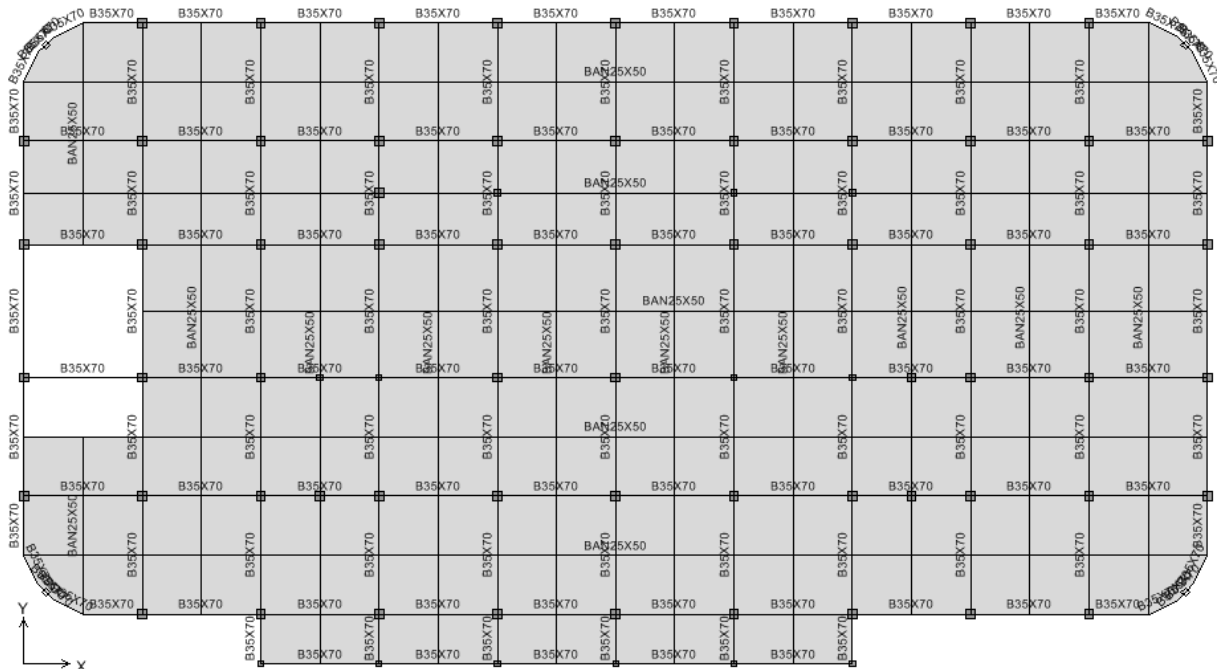


Figure 11. 2nd floor planning

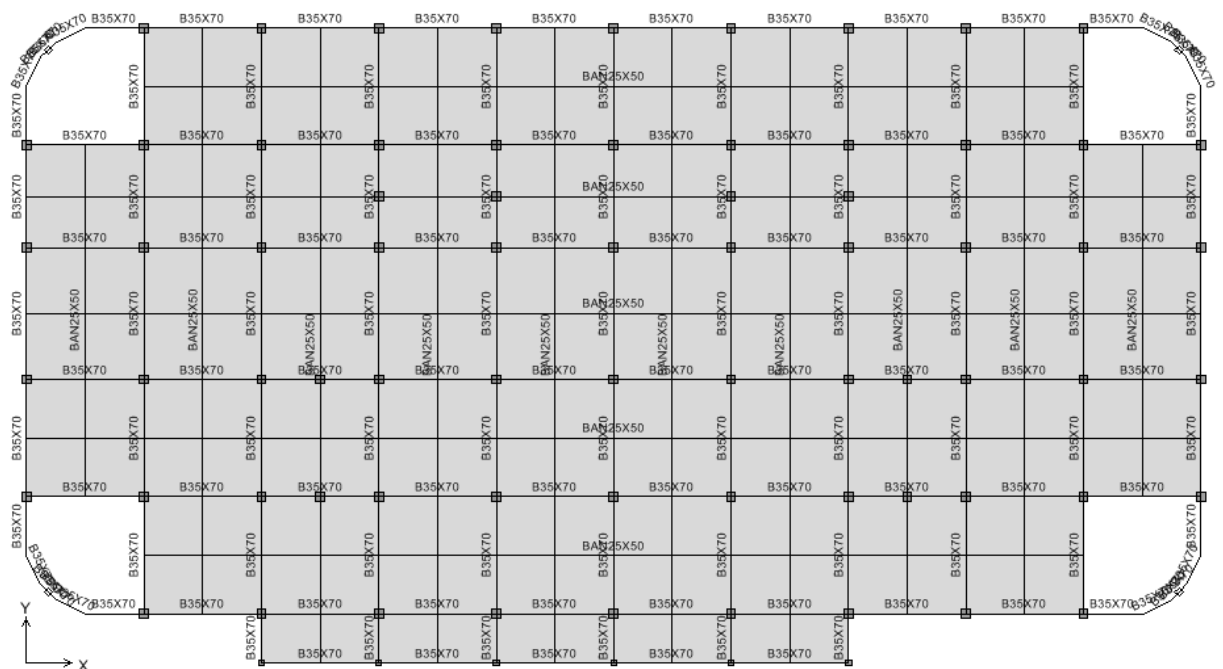


Figure 12. 3rd floor planning

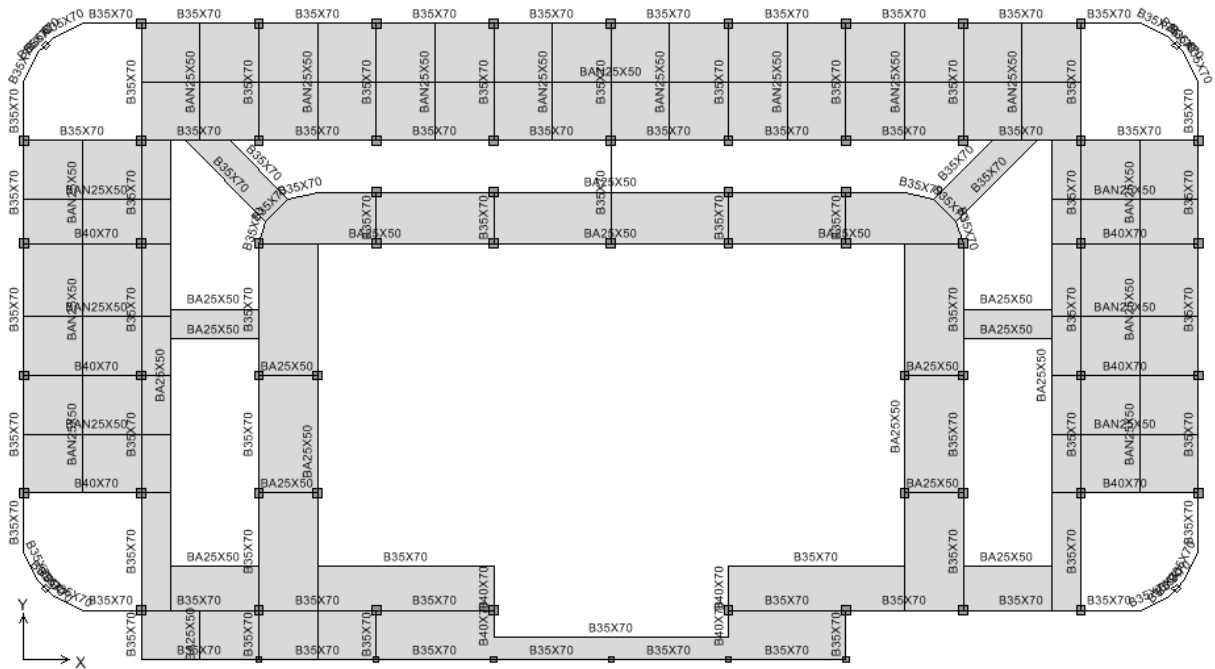


Figure 13. Floor planning 3.1

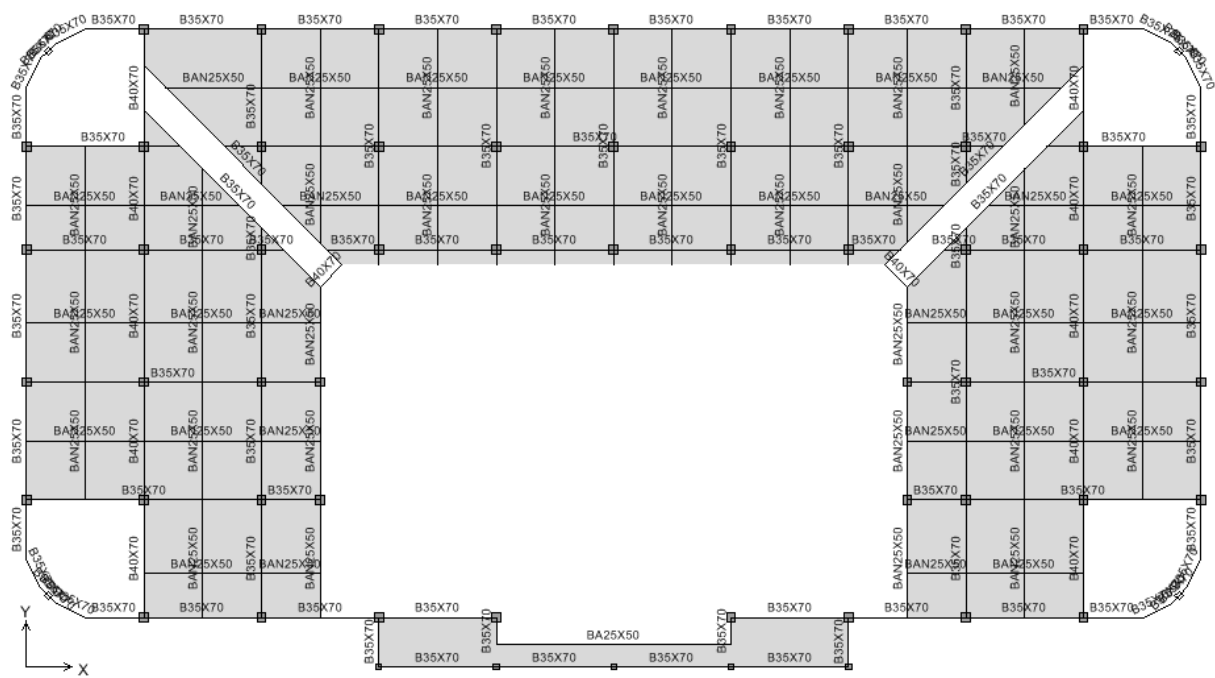


Figure 14. Grandstand floor planning

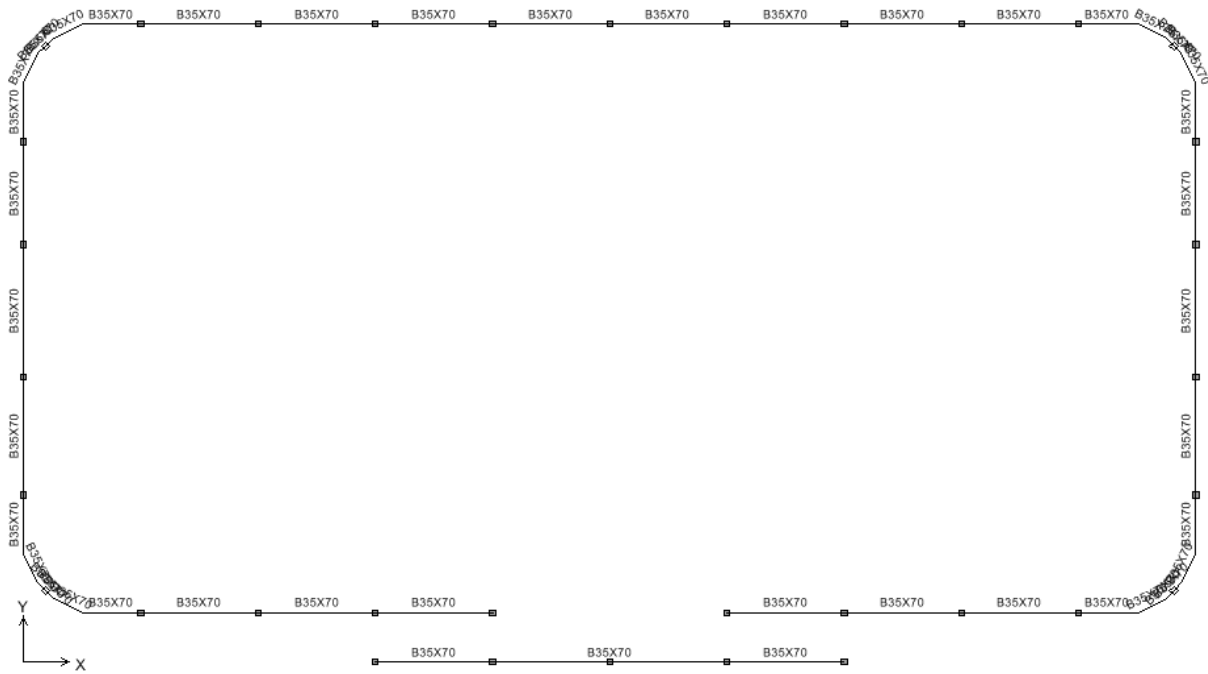


Figure 15. Roof floor Planning

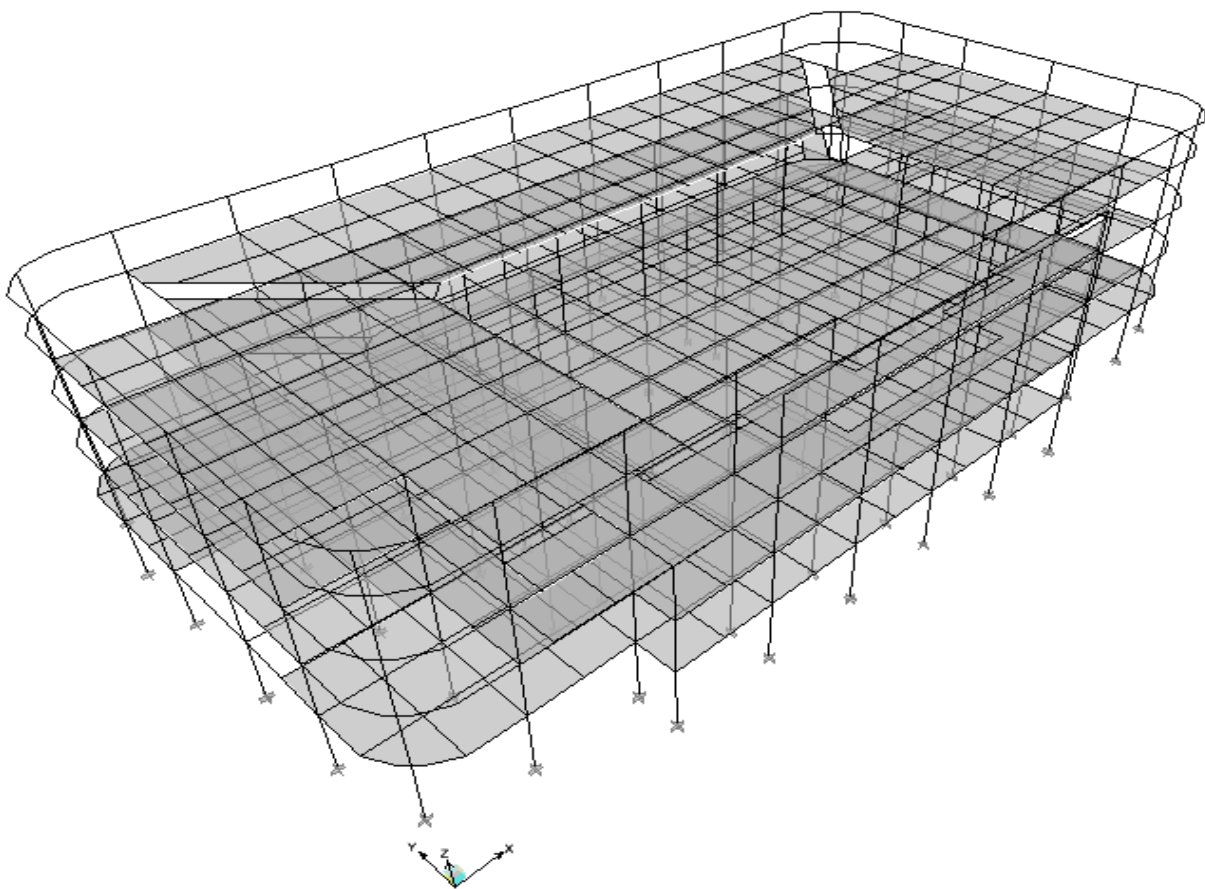


Figure 16. Three-dimensional Modeling

b. Dead Load and Live Load

Dead load is the load from all permanent building elements, including fixed equipment that is an integral part of the building. The live load on the building floor is given as 2.5 kN/m² and the live load on the grandstand floor is given as 5 kN/m². The application of this live load is based on the regulations in force in Indonesia regarding loading, specifically the Load Planning for Houses and Buildings (PPURG) 1987 regulations. Then, the dead load is divided into two parts, namely, structural dead load and additional dead load. Structural dead load is the self-weight of structural elements consisting of columns, beams, and slabs, calculated automatically in the Etabs program by providing a self-weight multiplier of 1 and additional dead load is the weight of non-structural elements that permanently load the structure.

c. Determination of the Earthquake Resisting System

The planned grandstand building is an office building that falls into risk category IV with an earthquake importance factor of 1.0. The earthquake load is calculated based on the Indonesian National Standard (SNI)

1726:2012.

d. Dynamic Structural Characteristics

In determining the dynamic characteristics of a structure, an analysis is conducted through the calculation of three-dimensional free vibrations, starting with the determination of the x, y, and z coordinate axes. 12 modes in the dynamic characteristics of a structure can be observed from the ratio of mass participation of capital. A total of 12 dynamic modes of structural characteristics can be shown in the mode of mass participation ratio U_x, U_y, and R_z which are shown in Table 6.

To prevent the building structure's response to earthquake loading that is dominant in the rotational direction, based on the results of the three-dimensional free vibration analysis, at least the first (fundamental) mode of motion must be dominant in translation. Based on Table 6, the results of the three-dimensional free vibration analysis show a dominant motion pattern in the first rotational mode. With these results, the analyzed grandstand building structure is a flexible structure. This structure also shows the results of the lateral earthquake force X in Table 7 and the lateral earthquake force Y in Table 8 which occurs at each floor height of the building.

Table 6. Dynamic Structure Characteristics

Variety Number	Natural Vibration Time (seconds)	Modal Participating Mass Ratio (% mass)			Dominant Movement Pattern
		UX	UY	RZ	
1	1,56	15,634	0,273	68,383	Rotation-Z
2	1,46	2,208	79,958	0,013	Translation-Y
3	1,44	64,719	1,946	15,955	Translation-X
4	0,54	0,058	13,180	0,115	
5	0,53	12,763	0,078	0,333	
6	0,50	0,274	0,061	10,961	
7	0,32	0,000	0,094	0,000	
8	0,29	0,000	1,148	0,002	
9	0,28	0,019	0,004	2,512	
10	0,27	0,021	0,000	0,009	
11	0,27	2,383	0,000	0,008	
12	0,27	0,000	0,999	0,008	

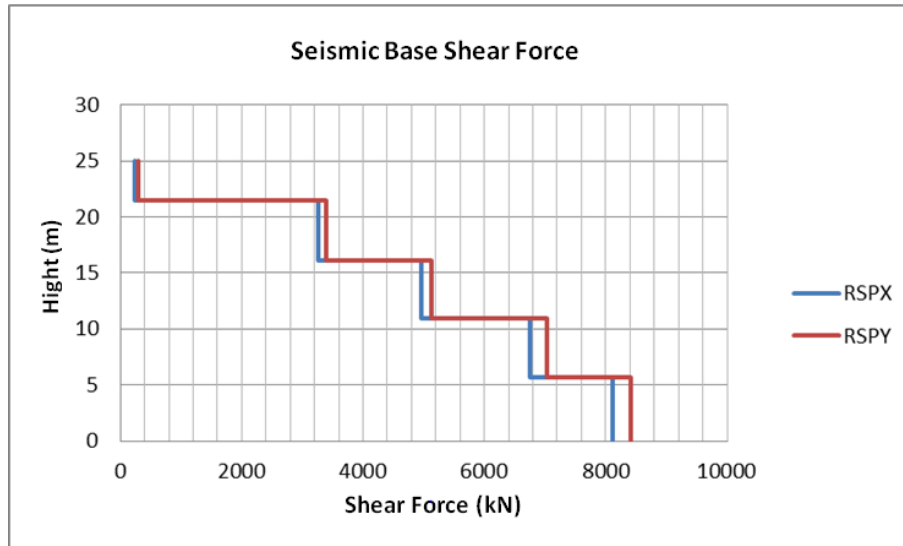
Source: ETABS Output

Table 7. Lateral Earthquake Force X

Floor	h _x (m)	h _x ^k (m)	w _x (KN)	w _x h _x ^k (KN.m)	C _{vx}	F _x (KN)	V _x (KN)
KAP Floor	24,98	62,13	227,605	14140,54645	0,004908	47,2512	47,2512
Grandstand Floor	21,48	51,19	22615,28	1157622,831	0,401789	3868,243	3915,494
3.1 Floor	16,1	35,36	20035,98	708464,1834	0,245895	2367,361	6282,855
3 rd Floor	10,9	21,44	31163,58	668027,2229	0,23186	2232,239	8515,094
2 nd Floor	5,7	9,33	35682,19	332914,4673	0,115548	1112,447	9627,541
Total				2881169,251			

Table 8. Lateral Earthquake Force Y

Floor	h_x (m)	h_x^k (m)	w_x (KN)	$w_x h_x^k$ (KN.m)	C_{vx}	F_x (KN)	V_x (KN)
Roof Floor	24,98	61,06	227,605	13897,58883	0,004894	47,59678	47,59678
Grandstand Floor	21,48	50,35	22615,28	1138658,292	0,400965	3899,703	3947,299
3.1 Floor	16,1	34,83	20035,98	697940,7222	0,245772	2390,323	6337,623
3 rd Floor	10,9	21,16	31163,58	659488,3081	0,232231	2258,63	8596,253
2 nd Floor	5,7	9,24	35682,19	329808,5457	0,116138	1129,536	9725,789
Total				2839793,457			

**Figure 17.** Seismic Base Shear Response Spectra

e. Global Structure Check

The natural vibration period of a building is an important component in the planning of earthquake-resistant buildings. In the planning of earthquake load calculations, the variable natural period of the building (T) is used to obtain the seismic response coefficient (C) for calculating the base shear force of the building. The Model of Seismic Base Shear Response Spectrum is shown in Figure 17. The minimum and maximum boundary values are as follows:

$$T_{\text{minimum}} = C_t h_{nx} \quad (1)$$

$$T_{\text{maximum}} = C_u T_a \quad (2)$$

$$C_u = 1,4$$

$$C_t = 0,0466$$

$$h_n = 24,98 \text{ m}$$

$$x = 0,9$$

$$T_{\text{minimum}} = (0,0466) (24,98) 0,75$$

$$T_{\text{minimum}} = 0,84$$

$$T_{\text{maximum}} = 1,4 \times 0,84$$

$$T_{\text{maximum}} = 1,18$$

$$T_{X_{\text{uncrack}}} = 1,06$$

$$T_{Y_{\text{uncrack}}} = 1,07$$

Checking T in the X direction:

$$T_{\text{minimum}} < T_{X_{\text{uncrack}}} < T_{\text{maximum}}$$

$$0,84 < 1,06 < 1,18 \text{ (Save)}$$

Checking T in the Y direction:

$$T_{\text{minimum}} < T_{Y_{\text{uncrack}}} < T_{\text{maximum}}$$

$$0,84 < 1,07 < 1,18 \text{ (Save)}$$

In each direction, the value of the structure's natural period (T) used is the value (T) obtained from the calculation results of the ETABS program for three-dimensional vibration analysis.

The natural period value of the structure is obtained from the calculation results, and the C_s value is calculated. The C_s value to be used is determined in advance by having a minimum limit and a maximum limit. Then the R value is taken as 8 in both directions because the structural system is the same, namely the Special Moment Bearing Frame System (SRPMK), then the I_e value is taken as 1.5 with the regulatory standard that the 5-storey tribune building designed is classified as a lecture building and belongs to a strong earthquake category area, namely risk category IV.

$$C_{s_{\text{minimum}}} = 0,004 \text{ SDS } I_e \geq 0,01$$

$$C_{s_{\text{minimum}}} = 0,004 \times 0,39 \times 1,5$$

$$C_{S_{\text{minimum}}} = 0,0528$$

$$C_{s \text{ calculation}} = \frac{S_{D1}}{T} \frac{R}{I_e}$$

$$C_{s \text{ calculation}(x)} = \frac{0,5}{1,06} \frac{8}{1,5}$$

$$C_{s \text{ hitungan}(x)} = 0,0888$$

$$C_{s \text{ calculation}(y)} = \frac{0,5}{1,07} \frac{8}{1,5}$$

$$C_{s \text{ calculation}(y)} = 0,0879$$

$$C_{s \text{ maximum}} = \frac{S_{DS}}{R} \frac{1}{I_e}$$

$$C_{s \text{ maximum}} = \frac{0,8}{8} \frac{1}{1,5}$$

$$C_{s \text{ maximum}} = 0,15$$

Checking C_s in the X direction:

$$C_{S_{\text{minimum}}} < C_{S_{\text{calculation}(x)}} < C_{S_{\text{maximum}}}$$

$$0,0528 < 0,0888 < 0,15 \text{ (Save)}$$

Checking C_s in the Y direction:

$$C_{S_{\text{minimum}}} < C_{S_{\text{calculation}(y)}} < C_{S_{\text{maximum}}}$$

$$0,0528 < 0,0879 < 0,15 \text{ (Save)}$$

C_s is calculated in each direction between the minimum and maximum C_s values. This C_s value is used, then the equivalent lateral shear force is calculated based on the calculated C_s value.

$$\begin{aligned} V_X &= C_{S_{\text{calculation}(x)}} W_t \\ &= 0,0888 \times 109497,0296 \text{ kN} \\ &= 9627,541 \text{ kN} \end{aligned}$$

$$\begin{aligned} V_Y &= C_{S_{\text{calculation}(y)}} W_t \\ &= 0,0879 \times 109497,0296 \text{ kN} \\ &= 9725,789 \text{ kN} \end{aligned}$$

The earthquake load analysis is conducted using the dynamic response method. The scale factor for the CQC dynamic response can be shown in Table 9.

f. Global Structure Check

The reduction values for bending and shear used are 0.8 and 0.75 based on the Indonesian National Standard (SNI) 03-2847-2002 Article 11.3, and the Indonesian National Standard (SNI) adopts the applicable provisions of ACI 318-99. Thus, the ACI 318-99 reduction value was adjusted into the ETABS analysis. The reduction values

used in the analysis are shown in Figure 18.

After analyzing the structure of this 5-storey grandstand building, then checking the global structure is carried out. Global structural checking is checking all structural element components such as beams, plates, and columns starting with the 1st floor structure to the 5th floor.

Global structural checking is carried out at the end after all the loading combinations given to this structure whether the analyzed structure shows safe or unsafe conditions. Safe condition means that after the structure is carried out through a run analysis in ETABS, it shows a color code as a sign of whether the structural elements are in a safe condition or not. ETABS software facilities show a color picture, namely red or green. If the red color is produced, the analyzed structure is in an unsafe condition, meaning that a review of the designed structure is needed. However, the structure of the 5-storey grandstand building analyzed after checking the global structure with the ETABS run analysis facility shows satisfactory results, namely green results as shown in Figure 19. Therefore, this structure is in a safe condition by showing the results of all structural element components in green. The green color results illustrate that the analyzed structure is capable of accepting a combination of all given loadings including loading in the strong earthquake lateral direction. Figure 19 shows that there are no structural element components in the beams, plates and columns that are overstressed. No red color is shown as a warning. Thus, the results of checking the global structure through the ETABS run analysis scientifically confirm that the results of this research that utilizes GFRP material as external reinforcement applied to reinforced concrete columns are very applicable to be applied in strong earthquake areas, namely the Mamuju city area in eastern Indonesia. Experimental results on the use of GFRP materials in concrete columns gave satisfactory results because concrete columns experienced an increase in axial strength. Concrete columns with additional GFRP material were then modeled on a high-rise building with a grandstand model to determine whether the condition of concrete columns reinforced with GFRP material could be directly applied through the ETABS program. In the results of the ETABS program produced through the output results, information is obtained that not only information on the strength of the building, but also on the stability of a structure is obtained because it is able to dissipate the energy of structural elements properly. The lateral displacement that occurs in the grandstand building under review does not exceed the safety limit and in the global check the structure does not experience overstress. The application of GFRP material in the analyzed building gives good results so that with these results it can strengthen scientifically the field of structures that the use of GFRP material in concrete columns not only functions as reinforcement and repair of damaged structures, but earlier it can be directly applied to the building to be reviewed, especially in earthquake-prone locations because the resulting structure can deform stably.

Table 9. Scale Factor

0,85 V ₁ (first response type)		V (CQC)		Scale Factor	
V _x (kN)	V _y (kN)	V _x (kN)	V _y (kN)	V _x (kN)	V _y (kN)
8266,92	8183,41	8113,56	8411,09	1,019	0,973

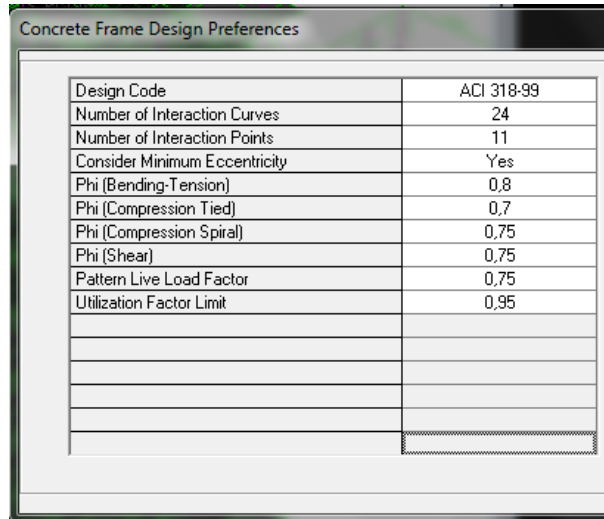


Figure 18. Adjustment of Reduction Factor According to SNI 03-2847-2002

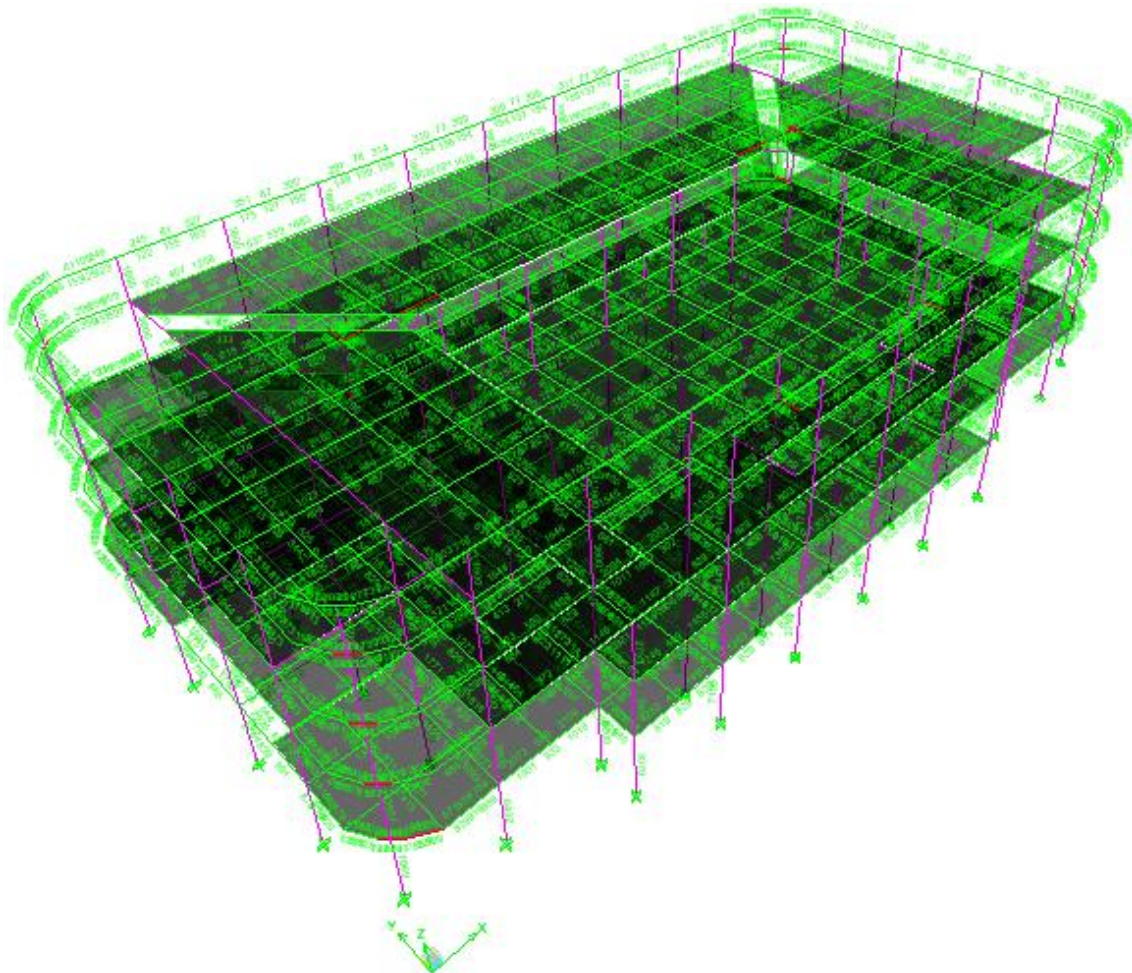


Figure 19. Global Structure Check Results

4. Conclusions

After conducting experimental tests in the laboratory regarding the use of GFRP reinforcement and an analysis of the 5-story grandstand building, it can be concluded as follows:

1. The results of laboratory testing show that the use of external GFRP reinforcement on reinforced concrete columns results in a very significant increase, as demonstrated by (PCL type) with an axial strength of 198 kN and (RCL type) with an axial capacity of 243 kN compared to (RC type) reinforced concrete columns without the use of external GFRP reinforcement, which only reached an axial capacity of 178 kN.
2. In direct application with ETABS software modeling for the analysis of a multi-story grandstand building using external GFRP reinforcement on reinforced concrete columns, significant stability and strength are demonstrated, marked by global structural checks showing no signs of overstress and able to withstand the lateral force of an earthquake.

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