ANALYSIS OF OPTIMIZATION OF CROSS-SECTIONS AND REINFORCEMENT OF BUILDING STRUCTURES BASED ON SNI 2847-2019 AND SNI 1726-2019

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Article Info

Article history:

Submitted August 3, 2024
Reviewed September 8, 2024
Published October 30, 2024

Keywords:

Analysis, ETABS, Overdesign, Eficiency.

ABSTRACT

Efficiency in structural design is important to optimize the use of materials and costs, while maintaining strength and stability to ensure the safety of the building. With construction design regulations constantly updated, careful and precise planning calculations are crucial. This study identifies overdesign in columns, beams, and foundations of existing buildings, and aims to determine more optimal and efficient dimensions and repetitions, resulting in stronger, more economical, and standard-compliant buildings. The research was conducted in a 4-storey office building with dimensions of 32 x 15,725 meters will be analyzed based on SNI 2847:2019, SNI 1726:2019, and SNI 1727:2020. The analysis was carried out using Microsoft Excel and ETABS. The results of the study showed that there was overdesign in the main column, main beam, and foundation. On a beam of 400mm x 650mm it produces an efficiency of 17.46%. The bending reinforcement requirement results in an efficiency of 21.785%. Meanwhile, the shear reinforcement and middle reinforcement are the same as the initial planning. In a 450mm x 700mm column it produces an efficiency of 16%. For shear reinforcement, an efficiency of 10% is obtained. As for the bending reinforcement, it is the same as the initial planning. In the foundation design, 4 square piles with dimensions of 450mm x 450mm and pilecap dimensions of 2600mm x 2600mm x 500mm with reinforcement requirements for the x direction D22-100 and the y direction D22-125. Resulting in a pilecap volume efficiency of 28.888%.

Available online at http://dx.doi.org/10.36055/fondasi

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1. INTRODUCTION

The rapid growth of the industry requires the construction of offices in large cities to support the industrial ecosystem. Office facilities are required for managerial activities, production coordination, management, and business partner services.[1] Modern and functional offices improve operational efficiency, attract investment, and drive economic growth. Technological advances in Indonesia have encouraged an increase in the need for building construction.[2] As time goes by, construction design regulations are constantly updated. Therefore, careful and precise planning calculations are needed to ensure a strong and economical building [3]. This research will discuss the reanalysis of building structures made of reinforced concrete materials with 4 floors. This building involves several structural elements such as columns, beams, floor slabs, roof plates, pile caps, and foundations using a bore pile foundation. Structural reanalysis is carried out based on the building design in the development project by referring to the SNI 1727-2020, SNI 2847-2019, and SNI 1726-2019 standards. The process of re-analyzing structures also involves the use of ETABS (Extended Three-Dimensional Analysis of Building Systems) software due to its ability to visualize structural models in detail and its ease of use. [4]

Based on the conditions in the field, visually the structural elements in the building are indicated to be overdesigned, namely on the main columns, main beams, and also the foundation, this makes the building heavier and will affect the earthquake force and durability of the building. Overdesign also results in the building being inefficient in terms of time and financing. So for some of these reasons, the author wants to provide an alternative design of the building to be more optimal and efficient. [5]

1.2 Literature Review

A reinforced concrete structure is a form of building structure that uses concrete along with an additional reinforcing material called reinforcement. The reinforcement is usually made of steel and placed in concrete to provide additional strength and increase the durability of the structure against certain loads [6]. Concrete is one of the most widely used materials in the world of construction. In Indonesia, almost 60% of the materials used in construction work are concrete which is generally combined with steel (composite) or other types [7] Concrete is a mixture consisting of sand, gravel, crushed stone, or other aggregates mixed with a paste made of cement and water, thus producing a mass similar to rock [8] . The process of manufacturing a reinforced concrete structure involves placing steel reinforcement inside the concrete mold before the concrete is poured. Once the concrete has hardened, the reinforcement and concrete work together to bear the load and provide structural strength. [9] SNI 1726:2019 defines that an upper structure is a structure that is located above the ground level, while a lower structure is one that is below the ground level. The upper structure includes elements such as columns, beams, floor slabs, and sloofs, while the lower structure includes the foundation [10]. Each of these components has a different function in a structure. For example, columns serve to pass off dead loads, live loads, and wind loads to the foundation and then to the ground. The strength of the building structure is very important to prevent the failure of the structure in withstanding the load it receives [11].

Beams are structural elements in construction systems that function to withstand forces in the form of bending moments, torque, and shear forces along their length in the horizontal direction [12]. With the bending moment, the beam needs reinforcement that functions to bear the bending moment that works along the beam, which is known as longitudinal (longitudinal) reinforcement. Meanwhile, to anticipate shear forces, the beams use transverse reinforcement (Sengkang reinforcement) which is installed along the beam at a certain distance according to the amount of shear force received. As for the axial force, actually the beam also receives the axial force of compression but the force is ignored, because it does not affect the behavior of the beam and its value is relatively very small. In other words, bending and shear are the most dominant internal forces that affect the behavior of beams in a building structure.
In condition 1 nominal moment can be written:

$$M_n = T_1 \times \left(d - {}^{a}/_{2}\right), M_n = A_{s1} \times f_y \times \left(d - {}^{a}/_{2}\right) \quad (1)$$

In the condition of 2 nominal moments can be written:

$$M_n = \left[(A'_s \times f'_s) - (A_s \times f_y)\right] \left(d - {}^{a}/_{2}\right) + (A'_s \times f'_y)(d - d') \quad (2)$$

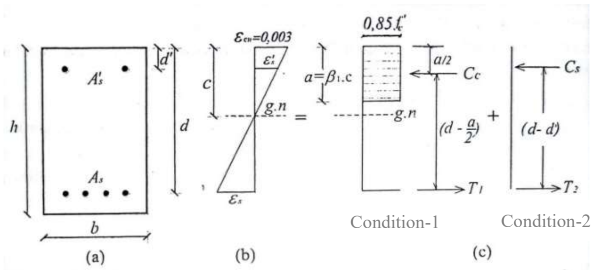

Figure 1. Balanced Strain Conditions on Beams [13]

Columns are vertical structural elements designed to withstand vertical loads and pass them down to the base of the building. The main function of the columns is to support the vertical loads of the floor, roof and other loads, then transfer them to the foundation. Columns are often strategically positioned within a building structure to distribute the load evenly and maintain the stability of the overall construction.

The column is a structural element that bears the combined load of axial compression and bending moment. Based on SNI 2847: 2019; Article 10.6.1.1 ; P-214, the minimum limit of the reinforcement ratio is 1% and the maximum limit is 8% (for general cases)[14]. In calculating the strength of the column, the column must first be identified in its type so that the way to calculate it is as it should be [15]. When it comes to its slimness, the columns are grouped into two types, namely short reinforced concrete columns and slender reinforced concrete columns. The fundamental difference between short columns and slender columns lies in the type of collapse. Short columns are classified as material collapse, while slim columns are classified as bent collapse.

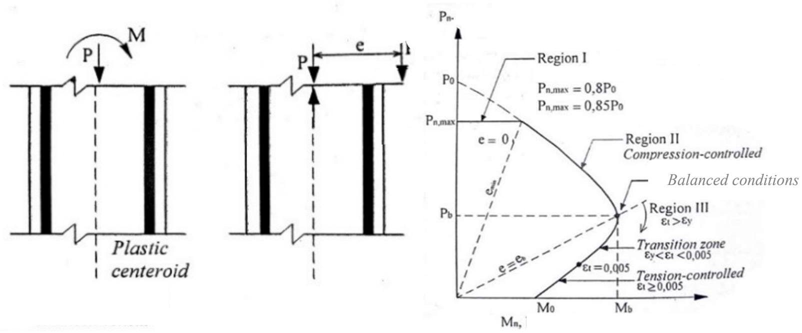

Figure 2. P-M Interaction Column [13]

The colı lement that receives a combination of loads in the form of axial pressure and moment. From the interaction of these two parameters (P&M), there are countless combinations of forces. The interaction of the axial pressure (P) and moment (M) is realized in a curve known as the P-M interaction diagram, as shown in Figure 3. At the equilibrium voltage can be expressed by the equation:

$$\frac{cb}{d} = \frac{0{,}003}{{fy}/{Es}+0{,}003} d = \left(\frac{600\ .\ d}{600+f_y}\right) \quad (3)$$

In Figure 3, it can also be seen that the correlation between P/M can be expressed in the sense of (e). When the section has just received an unusual compressive load, the column will be affected by the compressive and the moment at the same time. A moment that arises due to the impact of an unusual pile. Furthermore, in the P-M interaction diagram, the vertical axis of the graph discusses the value of e = 0 and the horizontal axis of the graph states e = ∞ [16]

The foundation structure is a structure that functions to channel the load from the upper structure into the soil so that the building can remain standing and stable [17]. The main function of the foundation is to evenly distribute the load of the building to the ground, thereby ensuring the stability and sustainability of the structure on it. The foundation plays an important role in preventing excessive decline or shift due to the applied load. In the condition of using a group of piles, especially involving axial forces and moments, it is necessary to specify the amount of axial value carried by each pile in one pilecap. The formulas that can be used are:

$$P_i = \frac{\Sigma P}{n} \pm \frac{M_y X}{\Sigma X^2} \pm \frac{M_x Y}{\Sigma Y^2} \quad (4)$$

The foundation is one of the key elements in the structure of a building and plays a vital role in the overall safety and performance of the building. Foundation design involves a good understanding of the properties of the soil on site, the applied loads, and structural engineering principles to achieve a solid and efficient foundation.

1.3 Load Analysis

a. Dead Load

Dead load is the load caused by the own weight of the permanent construction elements of a building structure. It includes the weight of materials such as concrete, steel, stone, or other permanent construction materials that make up parts of the structure. Dead loads are fixed and do not change over time, unless there is a permanent change in the structure. In Table 1 There are several dead loads on the roof plate.

Table 1. Dead Load on the Roof (SNI) [18]

Information	Weight	Unit	SNI 1727:2020
Ceiling and suspension	0.008	kN/m²	Page 280
Sanitation	0.10	kN/m²	Page 280
Mechanical and electrical	0.19	kN/m²	Page 280

b. Live Load

Live load is a load that comes from human activities or activities in or around a building. These loads are dynamic and can change over time, as they involve the movement of people, furniture, equipment, and other loads that arise as a result of daily activities. This live load must be calculated and included in the planning and design of the structure to ensure that the building is able to withstand all the loads that may arise during its use. The calculation of live load is an important factor in ensuring the safety, comfort, and durability of the building structure against various human activities and the load arising from daily activities.

c. Earthquake Load

Earthquake load is the lateral force or vibration generated by an earthquake and applied to a structure. Earthquakes create seismic waves that can cause horizontal movement on the ground, and building structures can experience significant dynamic forces in response to these vibrations. Earthquake load is measured in earthquake acceleration and is expressed as the relative acceleration between the ground and the structure. The earthquake load received by the building structure is the energy released during an earthquake. There are several methods to analyze earthquake loads on building structures, namely the equivalent static and response spectrum (RS) methods [17]. The earthquake load to be used refers to SNI 1726-2019 concerning Earthquake Resistance Planning Procedures for Building and Non-Building Structures [3]. In controlling the results of the structural analysis after being given all the loads, it is by determining the deviation. Determination of inter-level deviations (Δ) should be calculated as the difference in deflection at the center of mass above and below the floor under review.[19]

2. METHODS

2.1 Research Data

In this study, a building consisting of 4 floors and a roof will be used. The dimensions of the building include height from the base, with a length of 32 meters, a width of 15,725 meters, and a height between floors of 4.2 meters for floors 1-3 and 3.2 meters for floors 4. The building has a shape that resembles a rectangle and functions as an office. The building will be re-analyzed based on SNI 2847:2019 on structural concrete, SNI 1726:2019 on earthquake resistance, and SNI 1727:2020 on minimum load. The use of standards is very important because there is an increase in earthquake force parameters in several areas, in addition to some of the requirements for loading live loads have also increased. As a result, the calculation of the structure will be different if using different standards [20]. The calculations were performed with Microsoft Excel 2021 and structural modeling using ETABS 18. The ETABS program simplifies the modeling and analysis of building structures with computer technology, simplifying the previously complex design and analysis process [21]. Visually, the structural elements of the building, including the main columns, main beams, and foundations, are suspected of being overdesigned, so the dimensions and reinforcement of these elements will be reviewed to determine the optimal dimensions and reinforcement needs.

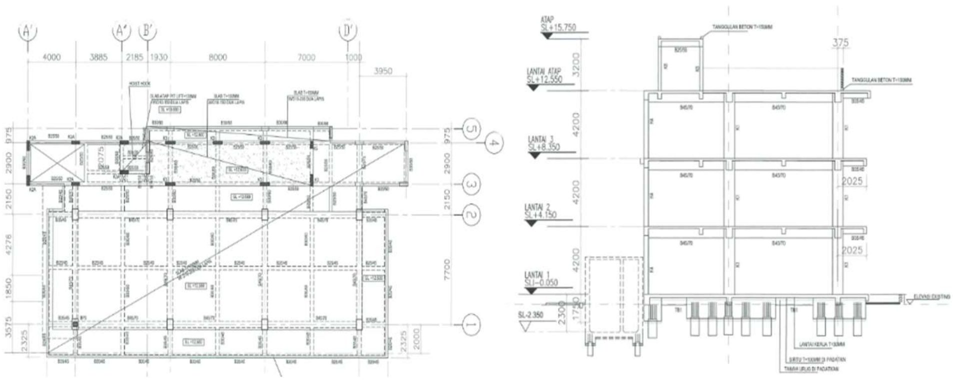

Figure 3. Floor Plan 1-3 (left), Section of Building Floor (right)

The quality of concrete (f'_c) used is 30 MPa, molten reinforcement with a diameter of <10mm is used steel melting strength (fy) of 240 Mpa, except for other quality roads, molten reinforcement with a diameter of ≥10mm is used steel melting strength (fy) of 420 Mpa, except for other quality roads.

2.2 Research Procedure

Broadly speaking, there are two stages of research that are carried out analytically, namely structural modeling and reanalysis of structural elements. The research procedure can be illustrated in Figure 4.

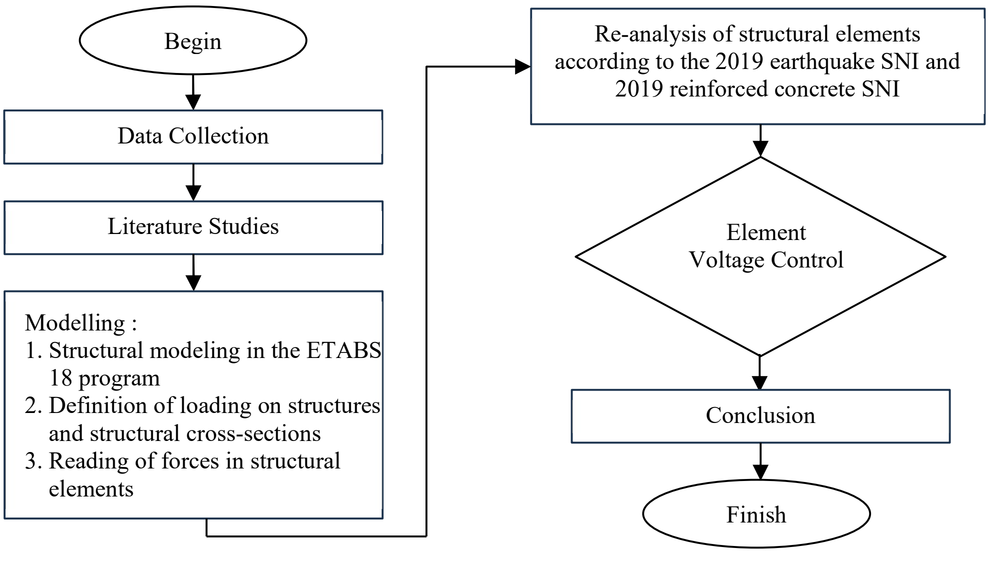

Figure 4. Research Flow Chart

a. Structural Modeling

In the early stages of the research, it is the creation of a structural model based on the plan drawing using the ETABS program. Then it is continued with the definition of material. The preliminary dimensions of structural elements such as slabs, beams, and columns refer to the project's existing data. The definition of gravity loads such as live loads, dead loads, and additional dead loads refers to SNI 1727:2020 which is input with load *pattern* and *load case features.* After the load definition, it is continued to define the load combination in the *load combination feature*. After the structure model has been created and the data has been inputted, then proceed with running an analysis (*run analysis*). The recapitulation results consist of moment output for further research.

b. Determining the Internal Styles and Design of Structural Elements

Determine the building weight, earthquake force, maximum deep force on structural elements including moment, shear force, and axial force on beams and columns from the results of the processed modeling. From the results of the ETABS program, it is also possible to determine the design of structural elements by referring to the cross-sectional area of the structural modeling.

c. Structural Element Analysis

In the second stage, calculation analysis was carried out on the main beam, main column and foundation based on the output generated from the previous modeling. At this stage, the cross-sectional diameter, reinforcement requirements and structural element reinforcement layout are calculated. Then a comparison is made with the existing condition of the structural elements while still referring to the required safety limits.

3. RESULTS AND DISCUSSION

3.1 Building Weight Per Floor

Table 2. Building Weight Per Floor

Floor	Manual				Etabs				Eror
5	554,60	KN	56591,75	kg	585,70	KN	59765,02	kg	-5,310
4	3786,07	KN	386333,59	kg	4018,42	KN	410043,30	kg	-5,782
3	6996,29	KN	713907,03	kg	7198,31	KN	734521,08	kg	-2,806
2	6866,73	KN	700686,58	kg	6689,63	KN	682615,26	kg	2,647
1	7816,20	KN	797571,22	kg	7599,01	KN	775408,80	kg	2,858
TOTAL	26019,88	KN	2652383,66	kg	26091,06	KN	2659639,54	kg	-0,273

The loads on a building structure include dead loads (weight of structural elements), live loads (temporary loads), and earthquake loads (due to plate shifts, landslides, or tsunamis). The magnitude of earthquake forces depends on the building's total weight, natural vibration period, importance factor, seismic reduction factor, and base seismic coefficient. [22]

3.2 Earthquake Load Calculation

In the calculation of earthquake load, the risk category of office facility buildings is II with an earthquake priority factor of 1. The earthquake load is calculated using the equivalent and dynamic static methods so as to obtain a design earthquake. The results of the earthquake load on each floor are obtained as shown in Table 2.

Table 3. Earthquake Load Per Floor

Elevasi	Static X	Static Y	Dynamic X	Dynamic Y	Design X	Design Y
19	226,776	226,776	72,469	51,544	231,610	190,506
12,6	1103,45	1103,45	341,617	299,050	1091,799	1105,272
8,4	1971,69	1971,69	589,896	502,170	1885,290	1855,995
4,2	2185,13	2185,13	683,713	591,222	2185,127	2185,127

Earthquake analysis methods for designing earthquake-resistant buildings are divided into two types: static analysis and dynamic analysis. The more precise the analysis of a structure's response to seismic forces, the more economical and reliable the design outcome.[23]
Equivalent static analysis is a simplified calculation of earthquake loads that results in a horizontal force due to inertia acting on a mass. The actual earthquake load originates from ground motion at the base, which propagates to the building elements. [24]

Table 4. Interfloor Junction Direction X

Floor	h (m)	δxe (mm)	δx (mm)	Δ (mm)	Δa/ρ (mm)	Information
Roof	15,75	4,363	23,9965	16,797	64,000	OK
Floor Roof	12,55	7,417	40,7935	2,382	84,000	OK
3	8,35	7,85	43,175	25,971	84,000	OK
2	4,15	3,128	17,204	17,204	83,000	OK

Table 5. Interfloor Junction Direction Y

Floor	h (m)	δye (mm)	δy (mm)	Δ (mm)	Δa/ρ (mm)	Information
Roof	15,75	4,057	22,3135	28,947	64,000	OK
Floor Roof	12,55	9,32	51,26	7,436	84,000	OK
3	8,35	10,672	58,696	25,229	84,000	OK
2	4,15	6,085	33,4675	33,468	83,000	OK

story drift in the design must be calculated as the maximum difference between points above and below the level along one edge of the structure. [25] The inter-story drift occurring when the section cracks must not exceed the established limits. This drift difference between floors must be multiplied by the Cd factor, which is determined by the selected structural type.[26]

3.3 Maximum Deep Force Recapitulation on Structural Elements

After running the structural modeling by the ETABS program, the results of the internal force that arise can be seen in Table 6.

Table 6. Maximum internal force on the beam

Beam Name	Support section		Span section	
	Vu (kN-m)	Mu (kN-m)	Vu (kN-m)	Mu (kN-m)
B 45/70	157,382	233,909	140,650	365,928

In building structures, bending moments, shear forces, and torsional moments significantly impact the behavior of beams in bearing loads. Due to these internal forces, beams require reinforcement known as bending, shear, and torsional reinforcement.[27] As the moment in the building structure increases, the dimensions of the beam elements used will also increase. This can be used to predict the values of internal force magnifications (bending moments, torsion, shear, and normal forces) based on the minimum bending ratio.[28]

Table 7. Axial force bending on the column

Condition	P (kN)	M2 (kN-m)	M3 (kN-m)
P max	-1951.061	81.730	-477.821
P min	-239.493	51.051	-151.034
M2 Max	-546.879	264.135	143.670
M2 Min	-1238.023	-286.448	-174.808
M3 Max	-757.463	-50.893	541.133
M3 Min	-1951.061	81.730	-477.821

The internal forces considered in the column include bending moments, shear forces, axial forces, and torsion. These four forces are analyzed to understand the column's response to the earthquake spectrum, ensuring the structure's resilience and stability against dynamic loads generated by seismic activity.[29]

To prevent column failure, earthquake-resistant structures must be designed using the strong column weak beam concept. Although plasticity in the ground floor columns cannot be avoided, the formation of plastic hinges in these columns requires sufficient ductility to allow the structure to undergo lateral deformation after yielding. [30]

3.4 Beam Analysis

The following are the results of the cross-sectional analysis on the main beam

Table 8. Comparison of Dimension of Initial Planning Beam with Redesign

Beam Name	Initial dimensions	Redesign Dimensions	Efficiency
B 45/70	450 mm x 700 mm	400 mm x 650 mm	17,46 %

Table 9. Comparison of Bending Reinforcement Needs of Initial Planning Beams with Redesign

Types of Beams		Moment	Return Results		Percentage of requirement (m')	
			Beginning	Redesign	Beginning	Redesign
B45/70	Support	M (-)	10D19	7D19	100 %	70,001%
		M (+)	7D19	5D19	100 %	71,428%
	Span	M (-)	7D19	5D19	100 %	71,428%
		M (+)	7D19	7D19	100 %	100 %
		Average			100 %	78,214%
		Efficiency				21,785%

Table 10. Comparison of Initial Planning Beam Shear Reinforcement Needs with Redesign

Types of Beams		Distance between reinforcements		Percentage of requirement (m')	
		Beginning	Redesign	Beginning	Redesign
B45/70	Support	100 mm	100 mm	100 %	100 %
	Span	150 mm	150 mm	100 %	100 %
		Average		100 %	100 %
		Efficiency			0 %

Table 11. Comparison of the Needs of the Middle Reinforcement of the Initial Planning Beam with Redesign

Types of Beams		Moment	Return Results		Percentage of requirement (m')	
			Beginning	Redesign	Beginning	Redesign
B45/70	Support	M (-)	2D13	2D13	100 %	100 %
	Span	M (+)	2D13	2D13	100 %	100 %
		Average			100 %	100 %
		Efficiency				0 %

From the results of the beam design in the re-analysis, the cross-sectional dimensions and bending reinforcement were smaller than the initial plan, and efficiency values of 17.46% and 21.785% were obtained respectively. As for the sliding reinforcement, and the middle reinforcement produce the same value as the initial planning. This proves that in the initial planning there was an overdesign of the cross-sectional dimensions and also the number of bending reinforcements used on the beam elements.

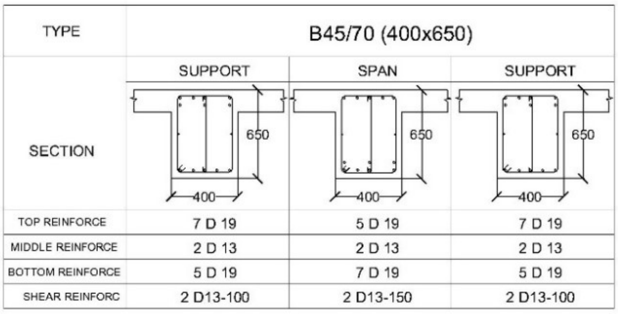

Figure 5. Beam Redesign Details

3.5 Column Analysis

After the analysis in the previous chapter, the planning of the structure of this building is on medium land whose type of Seismic Design Category is D, so it uses a Special Moment Bearer Frame System (SRPMK). In this analysis of the structure of the building, the type of column reviewed is a column of 450 mm x 700 mm. The column reviewed is based on the largest axial force (P) value of the loading combination. After checking the ETABS output, the column is in story 2 or on the ground floor, precisely in column C63.

The following are the results of the analysis in the SP Column application

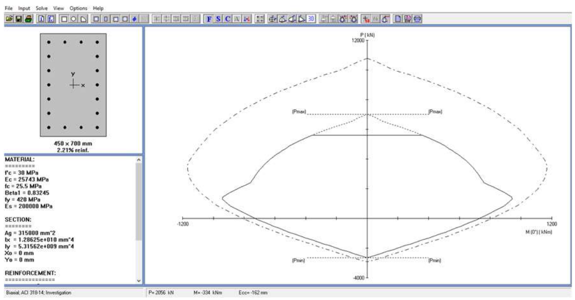

Figure 6. Main Column Interaction Diagram

The following are the results of the cross-sectional analysis in the main column

Table 12. Comparison of Initial Planning Column Dimensions with Redesign

Column Name	Initial dimensions	Dimensions redesign	Efficiency
B 45/70	500 mm x 750 mm	450 mm x 700 mm	16 %

Table 13. Comparison of Bending Reinforcement Needs for Column Bending Initial Planning with Redesign

Column Type		Return Results		Percentage of requirement (m')	
		Beginning	Redesign	Beginning	Redesign
C63	Support	18D22	18D22	100 %	100 %
	Span	18D22	18D22	100 %	100 %
	Average			100 %	100 %
	Efficiency				0 %

Table 14. Comparison of Initial Planning Column Shear Reinforcement Needs with Redesign

Type		Distance between reinforcements		Percentage of requirement (m')	
		Beginning	Redesign	Beginning	Redesign
C63	Support	100 mm	100 mm	100 %	100 %
	Span	100 mm	125 mm	100 %	80 %
	Average			100 %	90 %
	Efficiency				10 %

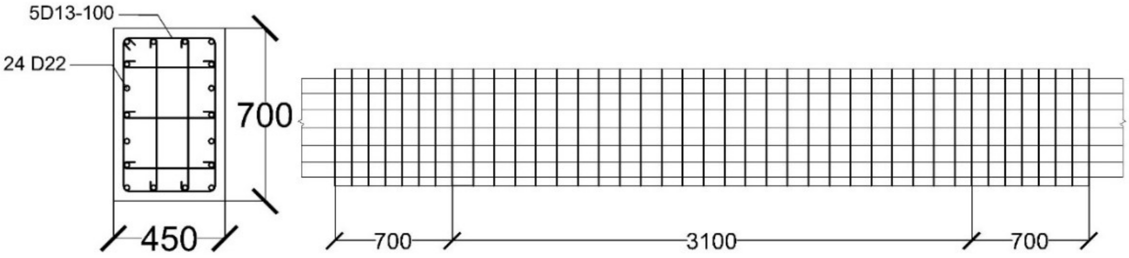

Figure 7. Redesign Column Details

From the results of the column design in the re-analysis, the cross-sectional dimensions and shear reinforcement were smaller than the initial plan, and efficiency values of 16% and 10% were obtained respectively. As for bending reinforcement, it produces the same value as the initial planning. This proves that in the initial planning there was an overdesign of the cross-sectional dimensions and also the number of shear reinforcements used on the column elements.

3.6 Foundation Analysis

The following are the results of the cross-sectional analysis on the Foundation

Table 15. Specification of Pile used

Pile beginning		Pile redesign		
N	Diameter	n	Long	Wide
4	600 mm	4	450 mm	450 mm

Table 16. Specification of Pilecap Reinforcement Used

Pilecap initial reinforcement		Reinforcement Pilecap redesign	
Direction X	Direction Y	Direction X	Direction Y
D19-125	D19-125	D22-100	D22-125

Table 17. Comparison of Initial Pilecap Dimensions with Redesign

Initial dimensions of pilecap			Pilecap Dimension redesign			Efficiency
Long	Wide	Tall	Long	Wide	Tall	
3000 mm	3000 mm	1300 mm	2600 mm	2600 mm	500 mm	28,888 %

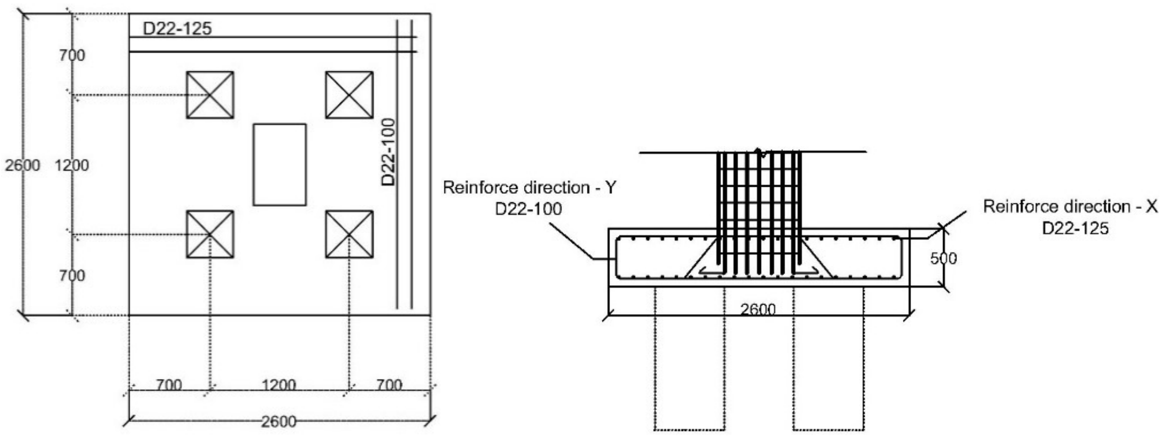

Figure 8. Detail Pilecap Redesign

From the results of the foundation design, the pilecap dimensions are slimmer than in the initial planning, with an efficiency value of 28.888%. This strengthens the initial suspicion in this study that there is an overdesign in the structural elements of this building, one of which is the foundation element.

4. CONCLUSION

Based on the results of the analysis and calculations carried out on the building, the conclusion was that the results of the beam design in the re-analysis obtained a cross-sectional dimension of 400 mm x 650 mm, resulting in an efficiency of 17.46%. For the reinforcement needs of the focal area, namely 7D19 on the upper reinforcement and 5D19 on the lower reinforcement. Meanwhile, the reinforcement needs for the field area are 5D19 on the upper reinforcement and 7D19 on the lower reinforcement. So that the bending reinforcement produces an efficiency of 21.785 %. As for the sliding reinforcement and middle reinforcement, it produced the same value as the initial planning, namely 2D13-100 in the pedestal area and 2D13-150 in the field area. As for the 2D13 central reinforcement in the field and support areas.

The results of the column design in the reanalysis produced a cross-sectional dimension of 450 mm x 700 mm, resulting in an efficiency of 16%. For shear reinforcement, namely for the D13-125 support area and for the D13-100 field area, an efficiency value of 10% was obtained. As for the bending reinforcement, it produces the same value as the initial plan, namely 18D22. The results of the foundation design produced 4 square piles with dimensions of 450 mm x 450 mm and pilecap dimensions of 2600 mm x 2600 mm x 500 mm with the need for reinforcement for the x direction D22-100 and the y direction D22-125. Resulting in a pilecap volume efficiency of 28.888 %.

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