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Evaluation of Upper Structure Strengthening Due to The Level Addition Based on SNI 2847-2013 Regulation (Case Study: PNJ Heavy Equipment Building)

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Abstract

The number of college students, who came to Java Island especially Jakarta City, makes the availability of land will be limited, one who get affected is campus building. The solution that can be done is increase the level of building and evaluate the structural elements ability of existing building. This study aims to determine the effect of additional levels on the internal forces and dimensions of the upper structure and evaluate the conducted by analyzing existing building and building that have been added level using ETABS software which refers to SNI 2847-2013 regulations. The results showed that after the addition of level, moments and shear forces on beam increase averaging 43%, while the column increase averaging 22%. In column axial forces have increased averaging 47%. After the addition of level, structure of Heavy Equipment building is known that there are several structural components which is not strong enough to withstand the load, namely Beams B, B1, and RB consecutively as much as 6 frames, 26 frames, and 12 frames; Columns K, K1, and K2 consecutively as much as 18 frames, 12 frames, and 8 frames. Both beams and columns were strengthened by FRP (Fiber Reinforcement Polymer) so the dimensions of the beams and columns did not change. The strengthening of structural elements is as follows: Beams B, B1, and B2 are strengthened with FRP tensile strength of 2800 MPa, FRP thickness of 1,2 mm, FRP width of 80 mm and the number of FRP used is 1 layer. Columns K, K1, and K2 are strengthened with FRP tensile strength of 4300 MPa, FRP thickness of 0,167 mm, FRP width of 500 mm and the number of FRP used is 16 layer for columns K&K2 and 24 layer for column K1.

Keywords
FRP, Internal Forces, Level Addition, Structural Strengthening.

1. Introduction

Java island is the island with the most populous population (Rusdiana 2001) and has the best universities in Indonesia. During the admissions period, many students from outside Java island came to continue their education. This will make Java island even more crowded, especially in big cities such as Jakarta.

According to population data for 2020, it is estimated that population in Indonesia until next year will be increasingly dense, if population growth increases, the availability of land will also be limited so that needs such as campus buildings will also be affected.

Campus building itself is a place used by college students to take higher education levels (Setyowati Ciptaningrum 2017). Therefore, we need a building that can be accommodate many students and add facilities so that they can study comfortably. However, not a few campuses have limited land, so the solution that is needed is to increase the level of building.

Due to the addition level of a building, this causes the earthquake force to be even greater. So it is necessary to evaluate the existing building structure to find out whether the building is still feasible with the initial condition of the structure or need to be strengthened if the structure is not strong enough to withstand the loads. (Bertambah et al. 2017)

1. 1. Identification of problems

Due to the addition level in a building, the seismic base shear force distributed on each floor also has an effect. The higher the floor level under review, the greater the earthquake force that will be received by the floor level. If the basic seismic shear force changes, the internal forces such as moment and shear will change. It is questionable whether the changes in these styles are still able to be borne by the existing structural elements. Structural elements that are not able to bear the load require analysis and evaluation of reinforcement so that the building is safe to use.

1. 2. Research Purpose and Objectives

The purpose of this study is to determine the effect of additional levels of the existing building. To achieve this aim, the following research objectives are defined.

1. Finding how does the addition of the building level effect the forces in the columns and beams.
2. To know the effect of additional level on column and beam dimensions.

Analysis the strengthening upper structure of building due to additional level.

2. Methodology

In this study, the data collection method used was a survey method consisting of field data (hammer test and beam column dimensions) and literature study. This research method uses quantitative research, where this method analyzes the modeling the building structure using the Special Moment Resistant Frame System (SRPMK) which refers to the regulations of SNI 2847-2013 and SNI 1726-2012.

This method has input, analysis, and output stages. At the input stage will be explained about the geometry of the structural elements. Determination of loads that work with 3-dimensional modeling. The analysis stages include structural modeling using ETABS 2013 software. The final stage is the output stage which discusses the adjusted detailing of the internal forces that occur in the building structure.

The final result of this research is expected that the building structure can withstand the loads and forces of additional level. If it is not strong, then proceed with evaluating the dimensions of upper structure of the building.

The research flowchart in this study is as follows:

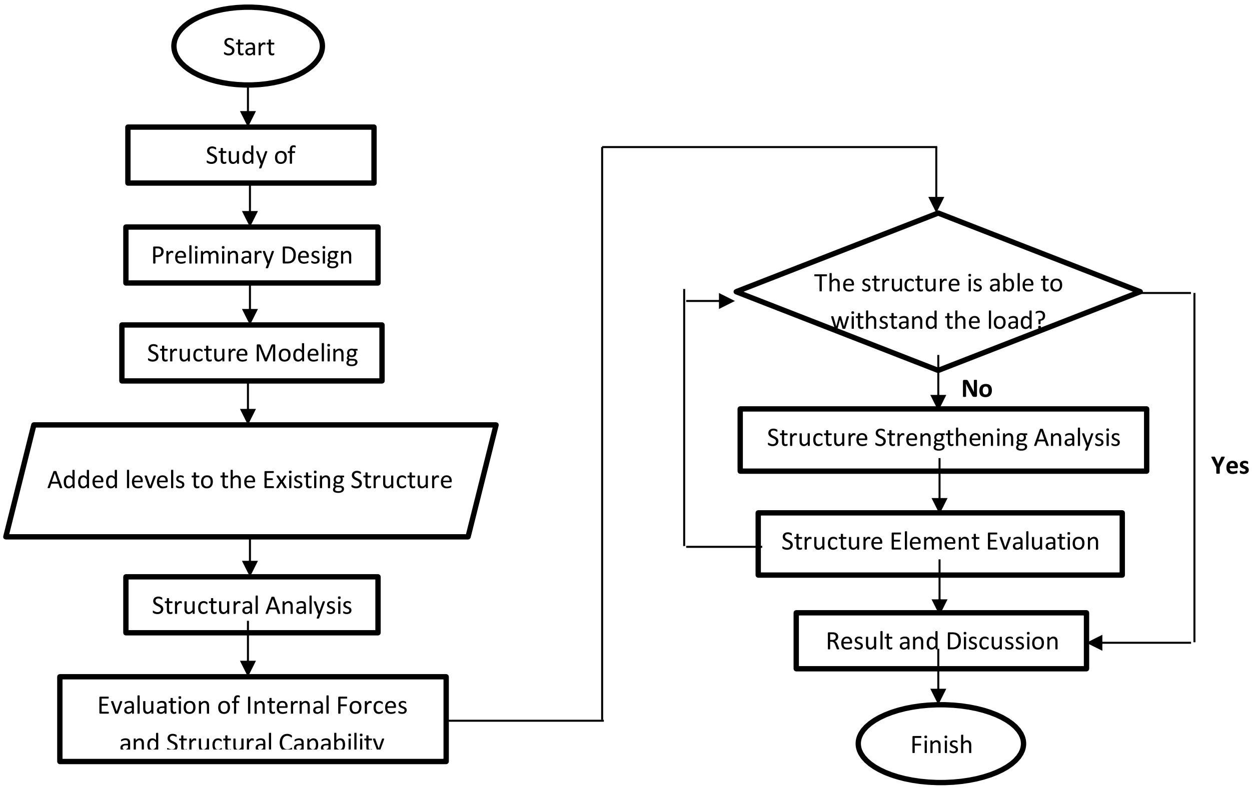

Figure 1. Research Flowchart

3. Result and Discussion

3.1. Object of Research

Building Function : Campus building
Number of floor : 3 floors
Height per floor : 4 m
Structure Material : Reinforced Concrete
Material Spec. : f'c 22 MPa for beam and slab
f'c 24 MPa for column
Existing Dimension : Beam B (40x80), B1 (30x50), B2 & B3 (20x40), RB (25x50)
Column K & K1 (40x60), K2 (30x50)

3.2. Preliminary Design

1. Beam

a. Main beam with span length (L) = 5 m and 6 m
   h min = 5000 / 14 = 357,14 mm ~ 500 mm
   h min = 6000 / 14 = 428,57 mm ~ 500 mm
   Then, b = 250 mm ~ 300 mm

a. Main beam with span length (L) = 10 m
   h min = 10000 / 14 = 714,28 mm ~ 800 mm
   Then, b = 400 mm

b. Ring Beam with
   h min = 5000 / 16 = 312,50 mm ~ 400 mm
   h min = 6000 / 16 = 375,00 mm ~ 400 mm
   Then, b = 200 mm

2. Column

Length and width of column are the minimum width of beam. Therefore, the same column size as the existing column is used, namely K1 400x600 and K2 300x500.

12) Slab

a. Net span calculation
   Ln max = The biggest L – B (beam) = 6000 – 400 = 5600 mm
   Ln min = The biggest L – B (beam) = 5000 – 400 = 4600 mm
   β = Ln max / Ln min = 5600 / 4600 = 1,2 < 2 → then the slab is 2 ways slab type

b. Minimum thickness calculation

$$\mathbf{H\ min} = \frac{\lambda_n\left(0{,}8+\frac{f_y}{1400}\right)}{36+9\beta} = \frac{5600\left(0{,}8+\frac{400}{1400}\right)}{36+(9\ .1{,}2)} = 129 \text{ mm}$$

$$\mathbf{H\ min} = \frac{\lambda_n\left(0{,}8+\frac{f_y}{1400}\right)}{36+5\beta(\alpha_m-0{,}2)} \rightarrow \mathbf{129\ mm} = \frac{5600\left(0{,}8+\frac{400}{1400}\right)}{36+5\ .1{,}2(\alpha_m-0{,}2)} \rightarrow \alpha m{=}2{,}055 > 2$$

Since αm = 2,055, the minimum slab thickness is 129 mm and cannot be less than 90 mm. So according to SNI 2847-2013 article 9.5.3.3, floor slab thickness that used is 130 mm.

3.3. Structural Modeling by ETABS 2013 Software

The existing structure of this building consists of 3 floors with building length is 36 meters, building width is 20 meters, and building height is 16,4 meters including the roof.

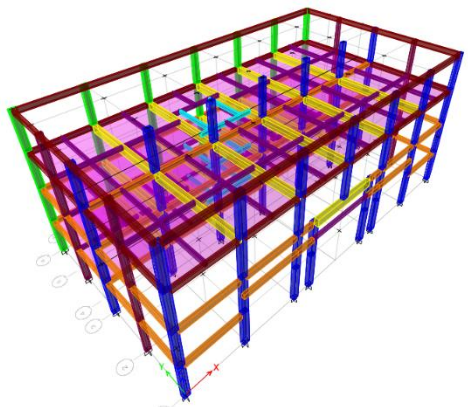

Figure 2. Structural Modeling in ETABS 2013 software

3.4. Loading

1. Load on Floor Slab

Table 1. Floor Slab Dead Load

Location	Component	Volume	Weight (kg/m2)	Weight (kN/m2)
Floor 2, 3, and 4	Ceramic	24 kg/m2 x 1	24	0,24
	Space	21 kg/m2 x 2	42	0,42
	Ceiling	-	11	0,11
	Hanger	-	7	0,07
	Ducting	-	20	0,20
TOTAL			104	1,04

Table 2. Floor Slab Live Load

Location	Utilization	Weight (kg/m2)	Weight (kN/m2)
Floor 2, 3 and 4	Public spaces and corridors that serve them	479	4,79
	TOTAL	479	4,79

Load on Beam

Table 3. Beam Dead Load (Wall)

Location	Component	Height (m)	Weight (kg/m2)	Weight (kg/m2)
F. 2,3,4	Wall	4,00	250	1000
Floor 2		2,00	250	500
F. 2 & 3		1,00	250	250

2. Additional Load on Second Floor Column (Overhead Crane)

Overhead crane load is designed as an impact load (dynamic load changes to static load) which refers to ASCE 7.10 rules. The results of these calculations are inputted into the column for P = 5788.4 kg and M= 2894.19 kg-m.

3. Load from Roof on Column

Load from roof consists of rain load, wind load, roof self-load, and live load which has been previously analyzed using ETABS software. The following is the roof load that is inputted to the column:

Table 4. Load from Roof on Column

Story	Load Case	PB kg-f	VB kg-f	PC kg-f	VC kg-f
Story 1	Dead	-1560,8	-1829,7	-1560,8	1829,7
Story 1	Live	-1700,0	-2045,0	-1700,0	2045,0
Story 1	HL	-1827,6	-2198,6	-1827,7	2198,6
Story 1	WKA	853,5	394,85	287,8	-819,1
Story 1	WKI	287,8	819,08	853,5	-394,7

4. Earthquake Load

Earthquake load is calculated using the static equivalent method because the building structure is regular. Coefficient value of earthquake priority factor (Ie)= 1.5, SS Depok = 0.75, S1 Depok = 0,35, SE site Class.

3.5. Beam Internal Forces Recapitulation

1. Moment Force

Recapitulation of comparison beam moment forces can be seen in tables 5 and 6 below:

Table 5. Beam Moment Forces Recapitulation

Beam Types	Location	Moment due to added level (kg-m)				Existing Moment (kg-m)			
		MDL	MLL	MEX	MEY	MDL	MLL	MEX	MEY
B1	End	8480	2843	20911	16131	8567	2881	12359	8472
	Middle	7507	2806	11146	9641	7505	2780	6615	5080
B2	End	10927	5742	6435	1790	10941	5750	3767	1072
	Middle	9773	4791	3661	1178	9772	4781	2147	627
B3	End	2637	1731	3703	1122	2634	1730	2119	651
	Middle	1563	795	1693	523	1553	790	967	303
B	End	27108	13856	15474	39553	26618	13649	10031	21246
	Middle	33654	18485	7411	19811	33432	18370	4840	10592

Table 6. Percentage Comparison of Beam Moment Forces

Beam Types	Location	Percentage of Moment Force Difference			
		MDL	MLL	MEX	MEY
B1	End Beam	-1%	-1%	41%	47%
	Middle Beam	0%	1%	41%	47%
B2	End Beam	0%	0%	41%	40%
	Middle Beam	0%	0%	41%	47%
B3	End Beam	0%	0%	43%	42%
	Middle Beam	1%	1%	43%	42%
B	End Beam	1%	1%	35%	46%
	Middle Beam	1%	1%	35%	47%

Description:
(+) : Moment force due to added level is bigger than existing moment
(-) : Existing moment is bigger than moment force due to added level
DL : Dead Load
LL : Live Load
EX : Earthquake in X-direction
EY : Earthquake in Y-direction

From tables 5 and 6 it can be seen that the average percentage of moments that arise in the beam due to dead load (DL) and live load (LL) between existing buidings and building that have been added level tends to be the same. Moments that arise due to earthquake loads in X-direction (EX) in building that have been added level are 40% greater than existing building. Moments that arise due to earthquake loads in Y-direction (EY) in building that have been added to the level are 45% greater than existing building.

2. Shear Forces

Recapitulation of comparison beam shear forces can be seen in tables 7 and 8 below:

Table 7. Beam Shear Forces Recapitulation

Beam Types	Location	Shear force due to added level (kg)				Existing Shear Force (kg)			
		VDL	VLL	VEX	VEY	VDL	VLL	VEX	VEY
B1	End	8121	2559	7207	6563	8139	2564	4255	3430
	Middle	5636	1968	7202	6563	5654	1997	4255	3430
B2	End	8230	4582	1949	549	8235	4589	1138	328
	Middle	6897	3414	1949	549	6902	3417	1138	328
B3	End	2707	1696	1246	452	2710	1697	714	260
	Middle	580	398	1219	410	583	398	699	237
B	End	21276	9534	3698	8521	21445	9627	2289	4575
	Middle	13661	6824	3544	8521	13522	6734	2289	4575

Table 8. Percentage Comparison of Beam Shear Forces

Beam Types	Location	Percentage of Shear Force Difference			
		V_{DL}	V_{LL}	V_{EX}	V_{EY}
B1	End Beam	0%	0%	41%	48%
	Middle Beam	0%	-1%	41%	48%
B2	End Beam	0%	0%	42%	40%
	Middle Beam	0%	0%	42%	40%
B3	End Beam	0%	0%	43%	42%
	Middle Beam	0%	0%	43%	42%
B	End Beam	-1%	-1%	38%	46%
	Middle Beam	1%	1%	35%	46%

Description:
(+) : Shear force due to added level is bigger than existing shear
(-) : Existing shear is bigger than shear force due to added level
DL : Dead Load
LL : Live Load
EX : Earthquake in X-direction
EY : Earthquake in Y-direction

From tables 7 and 8 it can be seen that the average percentage of shear that arise in the beam due to dead load (DL) and live load (LL) between existing buidings and building that have been added level tends to be the same. Shear that arise due to earthquake loads in X-direction (EX) in building that have been added level are 40% greater than existing building. Shear that arise due to earthquake loads in Y-direction (EY) in building that have been added to the level are 44% greater than existing building.

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3.6. Column Internal Forces Recapitulation

1. Moment Force

Recapitulation of comparison column moment forces can be seen in tables 9 and 10 below:

Table 9. Column Moment Forces Recapitulation

Column Types	Location	Moment due to added level (kg-m)				Existing Moment (kg-m)			
		MDL	MLL	MEX	MEY	MDL	MLL	MEX	MEY
K	Outer edge	6707	3895	29221	33627	4652	1770	15394	19719
	Inner side	21179	10957	27613	34979	22288	11516	17646	20443
K1	Outer edge	4602	1720	24892	30758	4694	1783	16375	18149
	Inner side	20832	11142	28840	34731	21343	11347	18822	20365
K2	Left Side	4226	2939	8461	14336	4461	3108	5517	8711
	Right Side	5045	2946	8456	17651	5275	3115	5516	10242

Table 10. Percentage Comparison of Column Moment Forces

Column Types	Location	Percentage of Moment Force Difference			
		MDL	MLL	MEX	MEY
K	Outer edge	31%	55%	47%	41%
	Inner side	-5%	-5%	36%	42%
K1	Outer edge	-2%	-4%	34%	41%
	Inner side	-2%	-2%	35%	41%
K2	Left Side	-6%	-6%	35%	39%
	Right Side	-5%	-6%	35%	42%

Description:
(+) : Moment force due to added level is bigger than existing moment
(-) : Existing moment is bigger than moment force due to added level
DL : Dead Load
LL : Live Load
EX : Earthquake in X-direction
EY : Earthquake in Y-direction

From tables 9 and 10 it can be seen that the average percentage of moments that arise in the column due to dead load (DL) in buildings that have been added level is 2% greater than existing building. Moment that arise in column due to live load (LL) in building that have been added level is 5% greater than existing building. Moments that arise due to earthquake loads in X-direction (EX) in building that have been added level are 37% greater than existing building. Moments that arise due to earthquake loads in Y-direction (EY) in building that have been added to the level are 41% greater than existing building.

2. Shear Force

Recapitulation of comparison column shear forces can be seen in tables 11 and 12 below:

Table 11. Column Shear Forces Recapitulation

Column Types	Location	Shear force due to added level (kg)				Shear force (kg)			
		VDL	VLL	VEX	VEY	VDL	VLL	VEX	VEY
K	Outer edge	9320	2556	17484	12067	4165	912	6844	7358
	Inner side	10340	5370	11543	13550	11385	5883	7543	8109
K1	Outer edge	2092	905	9843	9843	2229	910	6165	6141
	Inner side	10273	5508	13358	13358	10889	5793	8027	8049
K2	Left Side	2086	1459	6787	6787	2272	1580	2195	3768
	Right Side	2232	1461	8280	8280	2473	1584	2043	4452

Table 12. Percentage Comparison of Column Shear Forces

Column Types	Location	Percentage of Shear Force Difference			
		VDL	VLL	VEX	VEY
K	Outer edge	55%	64%	61%	39%
	Inner side	-10%	-10%	35%	40%
K1	Outer edge	-7%	-1%	32%	38%
	Inner side	-6%	-5%	33%	40%
K2	Left Side	-9%	-8%	36%	44%
	Right Side	-11%	-8%	32%	46%

Description:
(+) : Moment force due to added level is bigger than existing moment
(-) : Existing moment is bigger than moment force due to added level
DL : Dead Load

LL : Live Load
EX : Earthquake in X-direction
EY : Earthquake in Y-direction

From tables 11 and 12 it can be seen that the average percentage of shear force that arise in the column due to dead load (DL) in buildings that have been added level is 2% greater than existing building. Shear forces that arise in column due to live load (LL) in building that have been added level is 5% greater than existing building. Shear forces that arise due to earthquake loads in X-direction (EX) in building that have been added level are 38% greater than existing building. Shear forces that arise due to earthquake loads in Y-direction (EY) in building that have been added to the level are 41% greater than existing building.

3. Axial Force

Recapitulation of comparison column axial forces can be seen in tables 13 and 14 below:

Table 13. Column Axial Forces Recapitulation

Column Types	Location	Axial force due to added level (kg)				Existing Axial Force (kg)			
		PDL	PLL	PEX	PEY	PDL	PLL	PEX	PEY
K	Outer edge	62172	16017	26733	19274	38597	7285	10511	8803
	Inner side	142090	60528	7783	17765	73605	29188	3831	8107
K1	Outer edge	47031	12787	18721	21127	33566	8951	6107	8596
	Inner side	111551	43885	11028	19607	77912	30630	5219	7711
K2	Left Side	53652	20555	5140	2102	37454	14035	2095	966
	Right Side	54052	20609	4592	1491	37589	14088	1801	599

Table 14. Percentage Comparison of Column Axial Forces

Column Types	Location	Percentage of Axial Force Difference			
		PDL	PLL	PEX	PEY
K	Outer edge	38%	55%	61%	54%
	Inner side	48%	52%	51%	54%
K1	Outer edge	29%	30%	67%	59%
	Inner side	30%	30%	53%	61%
K2	Left Side	30%	32%	59%	54%
	Right Side	30%	32%	61%	60%

Description:
(+) : Moment force due to added level is bigger than existing moment
(-) : Existing moment is bigger than moment force due to added level
DL : Dead Load
LL : Live Load
EX : Earthquake in X-direction
EY : Earthquake in Y-direction

From tables 13 and 14 it can be seen that the average percentage of axial force that arise in the column due to dead load (DL) in buildings that have been added level is 34% greater than existing building. Axial forces that arise in column due to live load (LL) in building that have been added level is 38% greater than existing building. Axial forces that arise due to earthquake loads in X-direction (EX) in building that have been added level are 59% greater than existing building. Axial forces that arise due to earthquake loads in Y-direction (EY) in building that have been added to the level are 57% greater than existing building.

3.7. Analysis of Existing Building Structures with Additional Level

1. Beam

The results of ultimate moment strength evaluation and ultimate shear force in the beam can be seen in table 15.

Table 15. Beam Evaluation Results

Beam	Floor	Type	Mu (kN-m)	ϕMn (kNm)	Description	Vu (kN)	ϕVn (kN)	Description
B24		B	489,41	498,36	OK	722,11	697,09	NOT OK
B25	1	B	484,01	498,36	OK	722,91	697,09	NOT OK
B6		B1	46,463	152,64	OK	395,34	375,30	NOT OK
B24		B	476,77	498,36	OK	718,06	697,09	NOT OK
B25	2	B	478,10	498,36	OK	720,45	697,09	NOT OK
B6		B1	68,924	152,64	OK	378,43	375,30	NOT OK
B24		B	423,45	498,36	OK	710,34	697,09	NOT OK
B25	3	B	413,06	498,36	OK	719,56	697,09	NOT OK
B6		RB	64,538	99,41	OK	284,75	272,15	NOT OK

From the analysis of moments and shear forces, it is known that beam is strong to withstand the moment but not strong enough to withstand the shear, so that beam B has 6 frames to be strengthened, B1 26 frames, and RB 12 frames.

2. Column

The results of stress ratio evaluation and minimum area of reinforcement in the column can be seen in table 16.

Table 16. Column Evaluation Results

Column	Floor	Type	Stress Ratio	Condition Ratio	Description	Reinforce. Area Required	Reinforce. Minimum Area	Description
C17		K	1,289	1	NOT OK	6802	2400	OK
C10	1	K1	1,533	1	NOT OK	2835	2400	OK
C24		K2	1,245	1	NOT OK	1701	1500	OK
C17		K	1,333	1	NOT OK	6802	2400	OK
C10	2	K1	1,489	1	NOT OK	2835	2400	OK
C24		K2	1,192	1	NOT OK	1701	1500	OK
C12		K	1,122	1	NOT OK	6802	2400	OK
C5	3	K1	1,098	1	NOT OK	2835	2400	OK
B25		K2	1,073	1	NOT OK	1701	1500	OK

From the results of ETABS analysis, it shows that several columns have a ratio value more than one. So that column K has 18 frames to be strengthened, K1 12 frames, and K2 8 frames.

3.8. Structure Strengthening Analysis

1. Beam

Strengthening analysis of beams B, B1, and RB using CFRP SIKA Carbodur S812 with tensile strength of 2800 MPa, FRP thickness of 1.2 mm, FRP width of 80 mm and the number of FRP used is 1 layer. The following table 17 shows the recapitulation of beam shear force after being given strengthening.

Table 17. Recapitulation of Beam Shear Strength

Beam	Floor	Type	Plan Shear Force Vu (kN)	Nominal Shear Force + CFRP ϕVn (kN)	CFRP layer
B24		B	722,112	774,36	1
B25	1	B	722,906	774,36	1
B6		B1	395,336	585,82	1
B24		B	718,055	774,36	1
B25	2	B	720,454	774,36	1
B6		B1	378,432	585,82	1
B24		B	710,335	774,36	1
B25	3	B	719,557	774,36	1
B6		RB	314,840	515,42	1

2. Column

Strengthening analysis of columns K, K1, and K2 using CFRP SIKA Wrap 301C with tensile strength of 4300 MPa, FRP thickness of 0,167 mm, FRP width of 500 mm and the number of FRP used is 16 layers for column K & K2 and 24 layers for column K1. The following table 18 shows the recapitulation of column strength after being given strengthening.

Table 18. Recapitulation of Column Stress Ratio Strength

Column	Floor	Column Type	Stress Ratio (ETABS)	Stress Ratio+CFRP	CFRP	
					sheet	sheet
C17		K (40x60)	1,289	0,821	2	16
C10	1	K1 (40x60)	1,533	0,968	3	24
C24		K2 (30x50)	1,245	0,636	2	16
C17		K (40x60)	1,333	0,964	2	16
C10	2	K1 (40x60)	1,489	0,859	3	24
C24		K2 (30x50)	1,192	0,659	2	16
C12		K (40x60)	1,122	0,814	2	16
C5	3	K2 (30x50)	1,098	0,877	2	16
C25		K2 (30x50)	1,073	0,885	2	16

4. Conclussion

1. Moments on beam increase averaging 43% and shear forces increase averaging 42%.
2. Moments and shear forces increase averaging 21% and 22%. While axial force increase averaging 47%.
3. Both beams and columns were strengthened by CFRP (Carbon Fiber Reinforcement Polymer) so the dimensions of the beams and columns did not change.
4. The number of strengthened beams and column is based on the type, namely, Beams B, B1, and RB consecutively as much as 6 frames, 26 frames, and 12 frames; Columns K, K1, and K2 consecutively as much as 18 frames, 12 frames, and 8 frames.
5. Beams B, B1, and B2 are strengthened by CFRP SIKA Carbodur S812 with FRP tensile strength of 2800 MPa, FRP thickness of 1,2 mm, FRP width of 80 mm and the number of FRP used is 1 layer.
6. Columns K, K1, and K2 are strengthened by CFRP SIKA Wrap 301C with FRP tensile strength of 4300 MPa, FRP thickness of 0,167 mm, FRP width of 500 mm and the number of FRP used is 16 layer for columns K&K2 and 24 layer for column K1.

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