NUMERICAL SIMULATION OF RETROFITTING WITH EXPANSION IN SUPPORT REINFORCE CONCRETE BEAM

Luki Hariando Purba[1,*], Salomo Simanjuntak[1], Bambang Supriyadi[2]

[1] *Jurusan Teknik Sipil Universitas HKBP Nommensen*
Jl. Sutomo No. 4A, Perintis, Kec. Medan Timur, Medan, Sumatera Utara 20235
[2] *Departemen Teknik Sipil Fakultas Teknik Universitas Gadjah Mada*
Jl. Grafika No. 2, Sinduadi, Mlati, Kabupaten Sleman, Yogyakarta 55281
[*] *Corresponding Author: lukihariando.purba@uhn.ac.id*

Abstract
Beam-strengthening innovations need to be developed considering the frequent occurrence of earthquakes in Indonesia to avoid structural failure. One of the innovations in strengthening existing beams is strengthening by expanding the beam support area. This research aims to determine the behavior of strengthening existing beams. The research methods used are theoretical analysis and finite element analysis. Theoretical analysis and FEA show that strengthening the P1 beam can increase the bending and shear moment capacity by more than 50%. FEA analysis shows that retrofitting of the P1 beam increases stiffness by 45%. Strengthening the P1 beam is also able to avoid failure at the beam-column connection.

Keywords: *retrofitting, capacity, bending, shear, stiffness, expansion*

INTRODUCTION

Indonesia cannot be separated from earthquake disasters (Hadisantono, 2002). As a result of the earthquake, many buildings collapsed due to the quake's force. Earthquakes generate repeated forces from all directions. One of the forces caused by an earthquake that must be considered when planning tall buildings is shear force. *Shear force* is a force that can cause a building structure to collapse suddenly without any prior warning. Shear forces due to earthquakes can occur in all structural elements. Many studies have been carried out in high-rise buildings to increase the strength of the building structure. Retrofitting is one way of strengthening a structure to remain stable when subjected to enormous forces (Tudjono et al., 2017).

Many researchers have retrofitted beams against shear forces to anticipate large forces due to earthquakes (Muda et al., 2021, Mahendra et al., 2022). Beam-column connections are something that needs to be considered when planning a high-rise building (Ristanto et al., 2019). If the ability of a beam-column connection to experience a sizeable shear force results in collapse, then this is called structural failure. The shear resistance of beam-column connections is significant when planning a high-rise building. Currently, many studies have been carried out in structural engineering to provide better knowledge of the behavior of reinforced concrete structures (Supriyadi, 2008). Two of them are shear force and bending force. Computer applications are currently the most reliable technology in planning and analyzing reinforced concrete building structures.

One of the existing apartments in the city of Yogyakarta was constructed with innovative strengthening with the beam support area's expansion as shown in Figure 1. This innovation is very unique and rarely occurs in high-rise buildings. This innovation is predicted to increase the beam's shear capacity and strength. Chaimahawan (2018) researched rectangular and triangular planar expansion at beam supports and proved that expansion in the support area significantly increased the shear capacity, strength, and strength of the beam. Chaimahawan, et al. (2008) research can be linked to the construction of existing apartments because they both show the same innovation, namely strengthening with expansion in the support area. The difference is that Chaimahawan, et al. (2008) research expanded the height of the cross-section of the beam supports, whereas the existing apartment construction expanded the width of the cross-section of the beam supports.


Before and after casting

Figure 1. Construction retrofitting beam on apartment in Yogyakarta

Based on this background, it is necessary to research how much capacity increase will be contributed by innovative expansion of the beam cross-sectional width. The author aims to research the behavior of beam strengthening with widening expansion in the beam support area. This research was carried out using numerical finite element analysis software methods.

RESEARCH METHODS

The finite element method is a very familiar way now to investigate the behavior of structural elements (Salathiel et al., 2016). The finite element method can also complete linear analysis and nonlinear analysis. This research requires analysis up to nonlinearity or until the element fails or is damaged. This research refers to one of the Yogyakarta apartment construction projects in 2019 where the beam construction was strengthened by expansion in the beam support area. Therefore, the software models the existing beam dimensions and beam retrofitting. Beam modeling must be pinned because the retrofitting is in the beam support area so it will show the effect of the retrofitting. The modeling of existing column beams is modeled to idealize clamp supports. The dimensions of the existing beams and columns can be seen in Figure 2 and Figure 3. This research also requires conventional beams as control beams for comparison. Beam P1 is a reinforced beam with expansion in the beam support area and beam BK is a control beam. The modeling in the software will be simulated as a cantilever beam because it is only modeled at half the span.

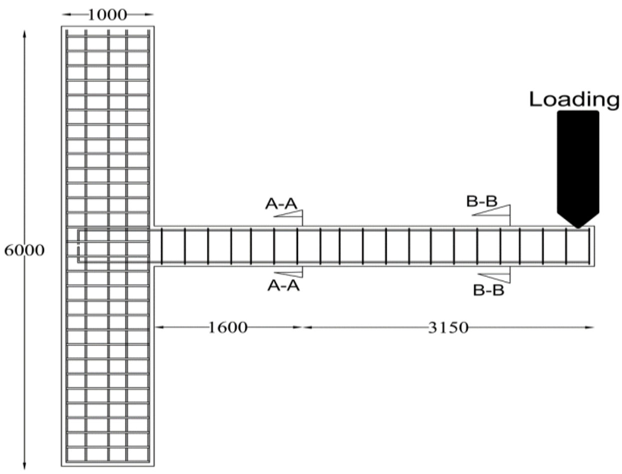

Figure 2. Beam-column dimension details (units in mm)

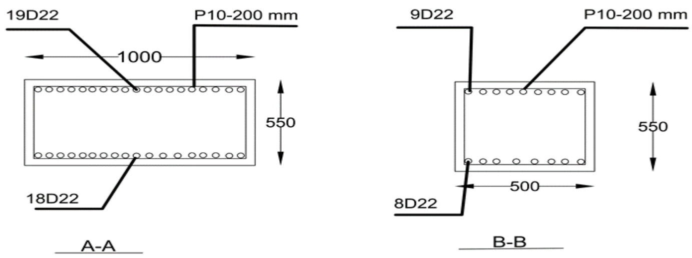

Figure 3. Beam section details (units in mm)

Based on SNI-2847-2019, concrete shear capacity and nominal moment can be calculated using the equations below:

$$V_c = 0{,}17 \times \sqrt{f_c'} \times \lambda \times b_w \times d \quad \text{.....(1)}$$

$$M_n = 0.85 f_c' ab(d - \tfrac{1}{2}a) \quad \text{.....(2)}$$

Where f_c' is the compressive strength of the concrete, *a* is the height of the compressed concrete block, *b* is the width of the section and *d* is the effective height of the section.

RESULTS AND DISCUSSION

The results of this research were taken based on theoretical and numerical analysis. Theoretically, expansion of the cross-sectional width in the support area can increase the bending moment and shear strength of the beam. After the theoretical results are obtained, the flexural strength and shear strength will be compared numerically.

Theoretical Analysis Results

Based on the results of theoretical analysis from Table 1, if failure occurs in the support area, the nominal moment capacity of beam P1 will be 1205.50 kNm while beam BK will be 560.41 kNm. The shear capacity of beam P1 is 517.91 kN while beam BK is 303.82 kN. Theoretically, it can be seen that the nominal moment and shear capacities of beam P1 are 113% and 70% more significant than beam BK.

Table 1. Theoretical Capacity

Type of Beam	Support Section			Strength Capacity				
	b	h	d	C_c (kN)	C_s (kN)	T_s (kN)	M_n (kNm)	V_n (kN)
P1	1000	550	496	798.28	2235.18	3033.46	1370.95	539.76
BK	500	550	496	159.66	1277.25	1436.90	642.89	316.64

Modeling Finite Element Analysis

Estimating existing beams and columns in Finite Element Analysis (FEA) software is done by inputting concrete property parameters. reinforcement and also cross-sectional dimensions. Simulations of beam P1 and beam BK can be seen in Figure 4 and Figure 5. The checkerboard image is a mesh that functions to divide one element into many elements. The type of element used is a rectangular element.

Load-Displacement Curve

Load-Displacement Curve behavior of beam P1 can be seen in Figure 6. The first crack occurred at a load of 107.52 kN and a displacement of 15.33 mm. In yield conditions, the load reaches 231.94 kN and the displacement is 61.15 mm. The maximum load is 259.70 kN and displacement is 200 mm. From this graph, you will also get the stiffness and ductility values of beam P1. Based on the ratio of load and displacement on the first crack, a stiffness value of 7.02 will be obtained, and based on the ratio of ultimate displacement to displacement yield, a ductility value will be obtained at 3.27. The next graph is the Load-Displacement Curve behavior of the BK beam which can be seen in Figure 7. The first crack occurred at a load of 61.41 kN and a displacement of 12.70 mm. In yield conditions, the load reaches 142.43 kN and the displacement is 52.93 mm. Maximum load is 163.40 kN and displacement is 200 mm. From this graph, it will be possible to determine the stiffness and ductility values of beam P1. Based on the ratio of load and displacement on the first crack, a stiffness value of 4.84 will be obtained, and based on the ratio of ultimate displacement to displacement yield, a ductility value will be obtained of 3.78.

Figure 8 is a comparison of the load-displacement curves of beam P1 and BK. This graph shows a very significant difference, thus showing that strengthening with expansion in the beam support area can increase capacity significantly. From this graph, it can be seen that the strength and stiffness of the P1 beam increased more significantly compared to the BK beam. In Table 2 it can be seen the comparison of the capacity of beam P1 with beam BK. During the first crack load, strengthening the P1 beam was able to increase the strength and stiffness by 75% and 45%. At yield, the strength of the P1 beam is 63% greater than that of the BK beam. This shows that many cracks occurred in beam P1. At maximum load, the strength of beam P1 is 59% greater than beam BK. Starting from the first crack load to the maximum, the behavior of beam P1 still shows significant differences. The ultimate bending moment of beam P1 is 1233.34 kNm and beam BK is 776.15 kNm so the bending moment capacity of beam P1 is 59% greater than beam BK. However, the ductility capacity of the P1 beam does not show a significant difference compared to the BK beam, so expansion in the support area of the beam does not increase the ductility.

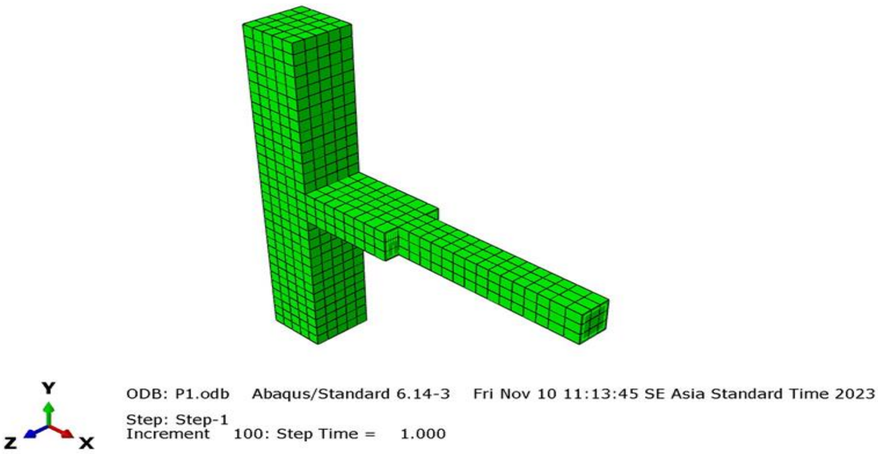

Figure 4. Simulation of beam P1 in FEA

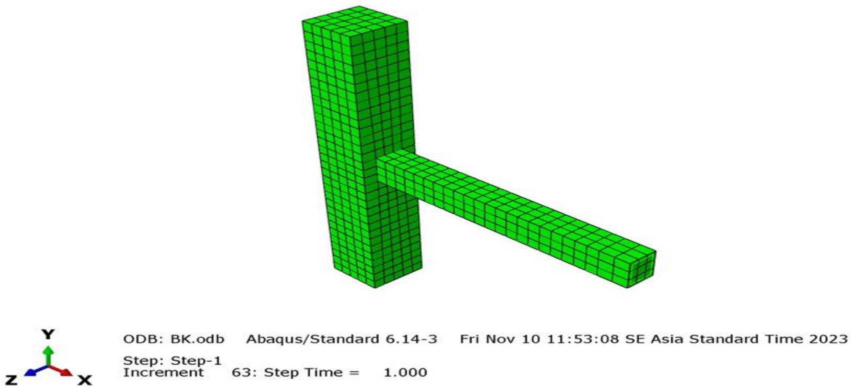

Figure 5. Simulation of beam BK in FEA

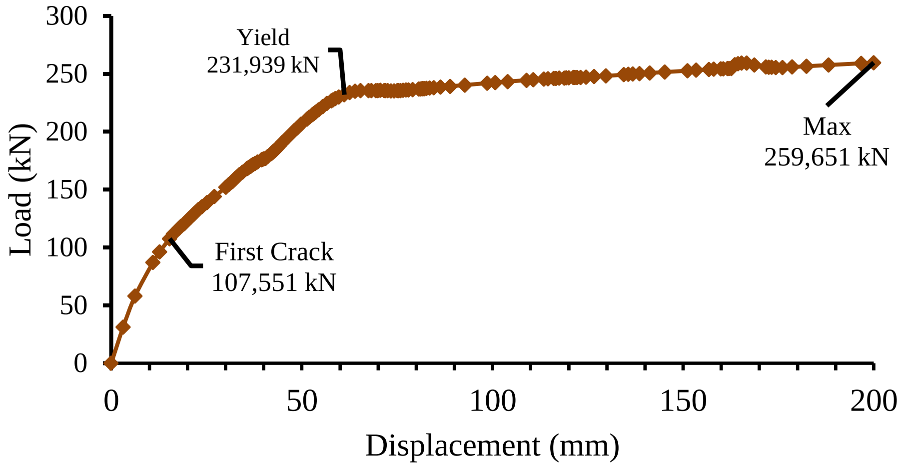

Figure 6. The load-displacement curve of beam P1

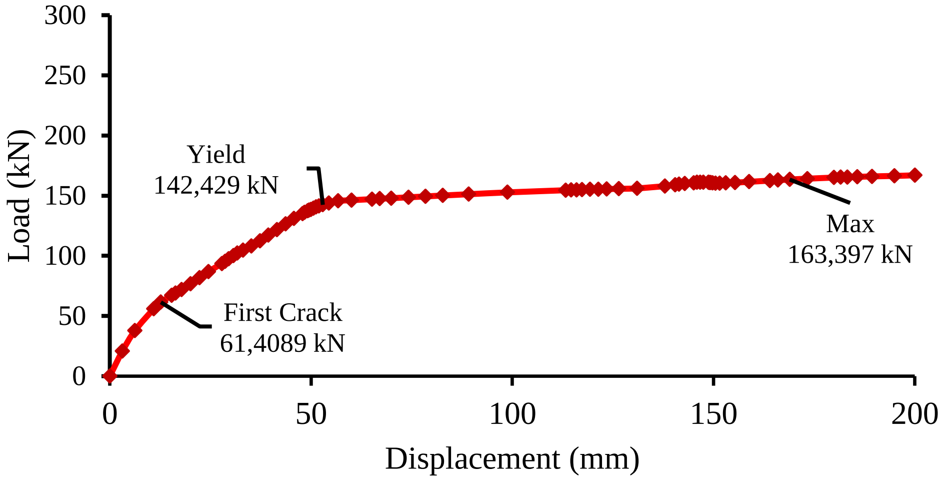

Figure 7. The load-displacement curve of beam BK

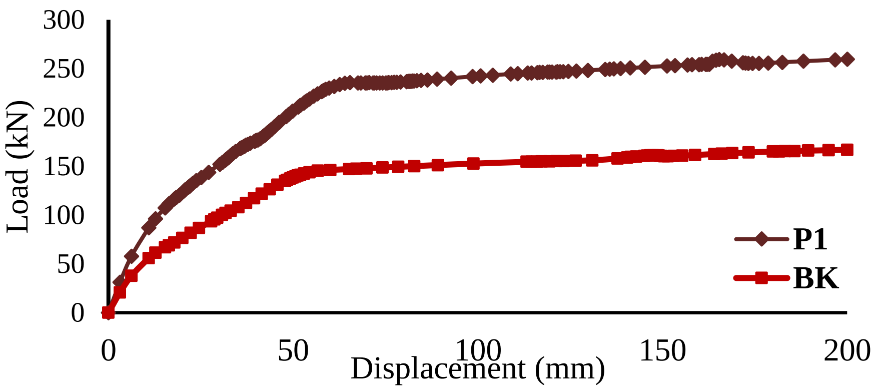

Figure 8. Comparison of load-displacement curve of beams P1 with BK

Table 2. Comparison of the capacity of beam P1 with BK

Capacity	P1	BK	Strength Enhancement
First Crack Load (kN)	107.55	61.41	75%
First Crack Disp (mm)	15.33	12.70	21%
Yield Load (kN)	231.94	142.43	63%
Yield Disp (mm)	61.15	52.93	16%
Maximum Load (kN)	259.65	163.40	59%
Stiffness (kN/mm)	7.02	4.84	45%
Ductility (kN/mm)	3.27	3.78	-13%
Moment Ultimate (kNm)	1233.34	776.15	59%

Comparison of Theoretical Analysis vs Numerical Analysis

In Table 3 it can be seen a comparison of the theoretical and FEA bending moment and shear capacities. The results of the theoretical analysis of the moment capacities of beams P1 and BK are 1370.95 kNm and 642.89 kNm, while in finite element analysis (FEA) they are 1233.34 kNm and 776.15 kNm. Theoretical moment capacity analysis and FEA do not show significant differences. The shear capacity of beams P1 and BK is theoretically found to be 539.76 kN and 316.64 kN, while in FEA it is 259.65 kN and 163.40 kN. The FEA shear analysis of beams P1 and BK is smaller than the theoretical analysis. Theoretical analysis and FEA both show that strengthening the P1 beam with expansion in the beam support area can increase the strength, namely the bending moment and shear capacity.

Stress Distribution Analysis

In Figure 9 and Figure 10, it can be seen the distribution of concrete stress in Beams P1 and BK. The maximum stress in concrete occurs in the bottom fiber area of the concrete. The collapse pattern of beam P1 can be seen in Figure 11. Beam P1 collapsed in the section after the support which is strengthened by expansion and is marked in red as shown in Figure 11. In contrast to the collapse pattern of beam BK, from Figure 12 it can be seen that the collapse of beam BK occurred at the end of the beam-column connection. These results indicate that expansion retrofitting in the beam support area will avoid collapse in the beam-column connection area. Based on theory, failure in the beam-column connection area should be avoided

Table 3. A comparison between theoretical vs numerical result

Capacity	Theoretical		Numerical	
	P1	BK	P1	BK
Moment (kNm)	1370.95	642.89	1233.34	776.15
Shear (kN)	539.76	316.64	259.65	163.40

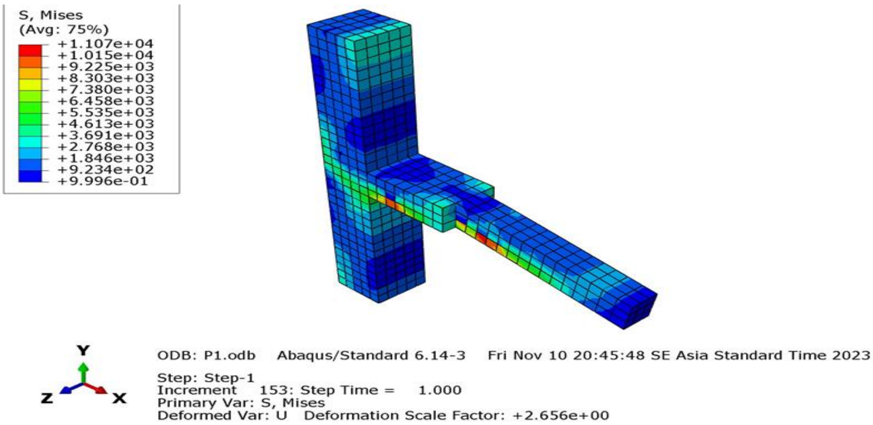

Figure 9. Stress distribution of concrete beam P1

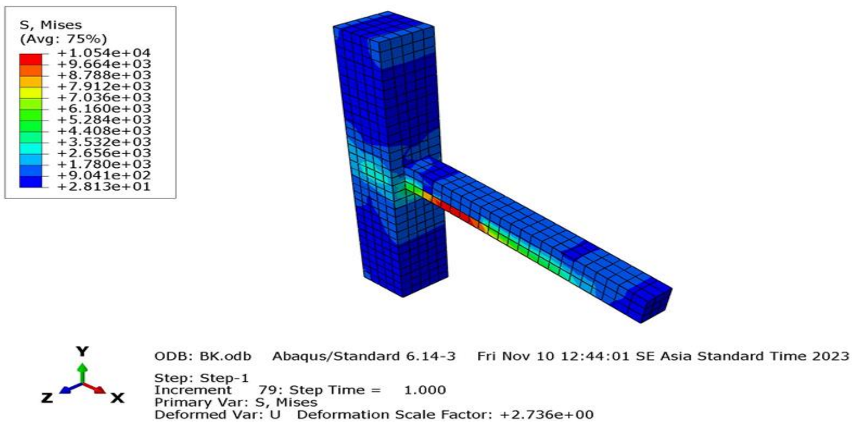

Figure 10. Stress distribution of concrete beam BK

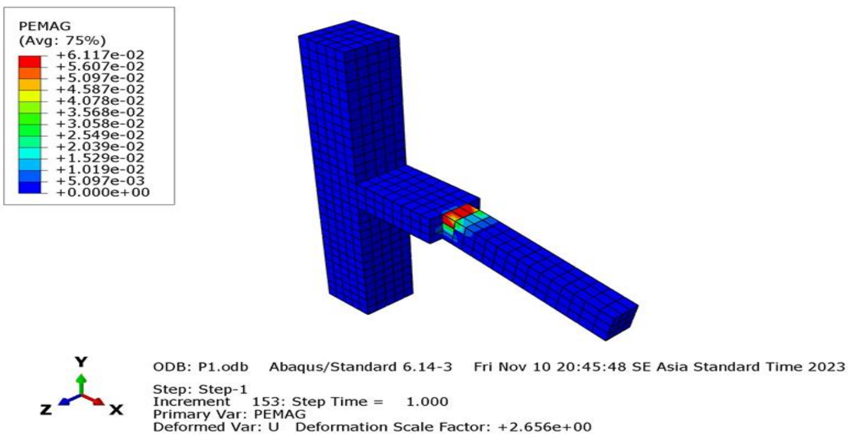

Figure 11. Failure pattern of beam P1

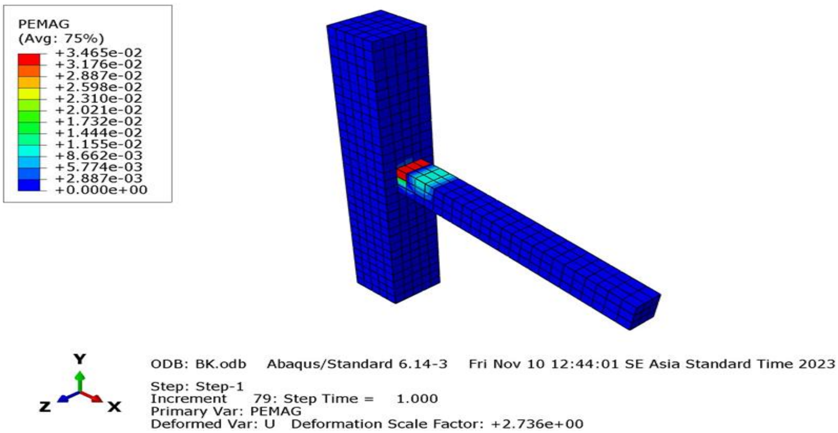

Figure 12. Failure pattern of beam BK

CONCLUSION

Expansion of the beam support area is one of the innovations that has been applied in the field. The aim of the research has been achieved, namely that strengthening the beam with expansion in the beam support area can increase the bending moment capacity, shear, and stiffness. Retrofitting with wide expansion of the beam cross-section shows a significant increase in capacity. Theoretical and FEA both show an increase in bending moment and shear capacity by more than 50%. FEA analysis shows that strengthening the P1 beam can increase stiffness by up to 45%. FEA analysis also shows that strengthening the P1 beam is also able to avoid failure in the beam-column connection area.

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