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Feasibility Study and Floor Additional Plan with Concrete Jacketing Strengthening Method

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ABSTRACT

Concrete Jacketing is a method of strengthening reinforced concrete structures that is applied to buildings to increase and improve their strength capacity. Concrete Jacketing is carried out by enlarging the existing reinforced concrete cross section with an additional layer of concrete which is also reinforced with reinforcement. The structure of the Taruna Warmadewa Vocational School building is planned to be given additional floors, from 2 floors to 3 floors. Prior to adding the floor, a feasibility study was carried out for testing the existing material, to determine the quality of the material to be used in the analysis. Based on the results of material testing of the existing structure, the structure of SMK Taruna Warmadewa needs to be strengthened. Therefore, concrete jacketing was chosen as an effective reinforcement method to increase the capacity of the structure to carry loads due to the addition of floors. The method of collecting data in carrying out a feasibility study and planning for additional floors in the Taruna Warmadewa Vocational School is the method of literature study, direct observation, material testing and modeling analysis. The analysis determined that concrete jacketing was required for all columns and two types of beams. Specifically, column dimensions were increased from 30 cm × 50 cm to 50 cm × 70 cm (K1), primary beams from 30 cm × 45 cm to 35 cm × 55 cm (B1), and secondary beams from 20 cm × 30 cm to 30 cm × 45 cm (B2). The pile cap foundation thickness was increased from 30 cm to 70 cm, with plan dimensions of 2 m × 2 m. For the new third floor, the design specifies columns of 45 cm × 45 cm (K1) and three beam types: 30 cm × 50 cm (B1), 25 cm × 40 cm (B2), and 20 cm × 30 cm (B3).

Keywords: Concrete Jacketing; Retrofitting; Structural Strengthening

1 Introduction

The increasing demand for vertical expansion of existing buildings in Indonesia, particularly in the education sector, necessitates a thorough understanding of structural integrity and reinforcement methods. The predominant use of reinforced concrete in construction provides a robust framework due to its high compressive strength, durability, and cost-effectiveness. This material's ability to combine the compressive strength of concrete with the tensile strength of steel reinforcement makes it particularly suitable for various architectural needs in Indonesia's urban landscape [1].

However, the aging of structures, especially those over 20 years old, often leads to material degradation that can significantly compromise their integrity, especially during seismic events [2]. This degradation underscores the necessity for comprehensive technical evaluations prior to any modifications or expansions. For structures that are otherwise in good condition but exhibit inadequate serviceability, appropriate reinforcement strategies are essential to prevent structural failure [3]. The case of the Taruna Warmadewa Vocational School exemplifies this need, as the proposed vertical expansion of its southern wing requires a detailed Building Feasibility Study to assess the existing structure's capacity for additional loads.

Concrete jacketing has emerged as a viable solution for reinforcing existing structures. This method involves encasing existing concrete elements with additional reinforced concrete, effectively enhancing both strength and ductility [4][5]. Studies have shown that concrete jacketing not only improves the load-bearing capacity of structural members but also reduces stress concentrations at critical points, thereby restoring structural integrity [6][7]. Given its advantages, including the availability of materials and ease of implementation, concrete jacketing is particularly well-suited for the planned expansion at the Taruna Warmadewa Vocational School.

The feasibility of vertical expansions in existing reinforced concrete structures hinges on a thorough understanding of the existing conditions and the application of effective reinforcement methods such as concrete jacketing. This approach not only addresses the immediate structural concerns but also aligns with the broader goals of sustainable urban development in Indonesia.

2 Data and Methods

2.1 Research Flowchart

The flowchart of the feasibility study and planning for adding a floor with the strengthening of the concrete jacketing structure in the building structure of the Taruna Warmadewa Vocational School on the South side is shown in Figure 1.

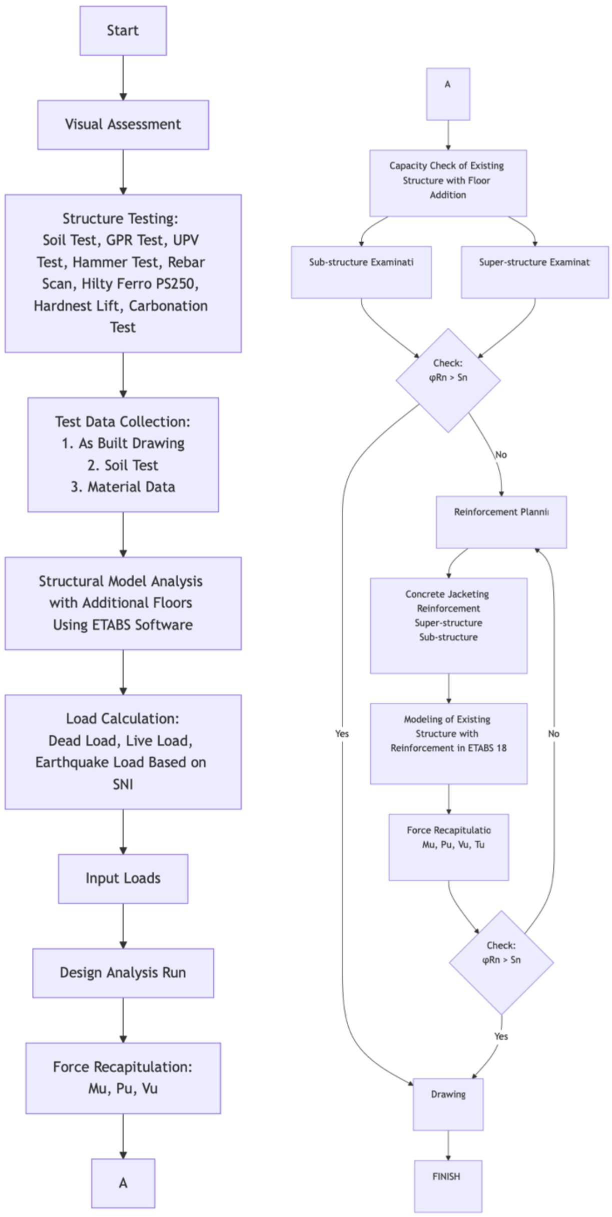

Figure 1. Planning Flowchart

The methodology for this research employs a comprehensive approach that integrates literature review, material testing, and structural analysis modeling, ensuring a thorough assessment of both existing conditions and proposed modifications.

Literature Study Method: The literature review method systematically examines academic sources, including journals, research articles, technical standards, and engineering textbooks, to establish a theoretical foundation for structural assessment and reinforcement strategies. This review ensures compliance with current building codes and engineering best practices, with particular emphasis on concrete jacketing applications in similar structural modifications [8][9][10].

Test Method: The testing method involves various physical assessments of the existing structure to determine critical material properties such as concrete strength, reinforcement conditions, and overall structural integrity. Non-destructive evaluations (NDEs) and selective core sampling are among the tests employed, providing essential data for subsequent analytical modeling [11][12]. These assessments are crucial for understanding the current state of the structure and identifying any deficiencies that may need to be addressed through reinforcement.

Model Analysis Methods: The model analysis method utilizes advanced structural analysis software to simulate building behavior under various loading conditions. This computational approach enables accurate predictions of internal forces, deformations, and potential failure modes under both current and proposed configurations. The analysis incorporates seismic considerations specific to Indonesian building requirements, ensuring that the proposed modifications will enhance the structure's resilience against seismic events [13][14]. The integration of these methodologies allows for a comprehensive evaluation of the structural modifications, ensuring that they are both effective and compliant with engineering standards.

2.2 Planning Data

The preparation of this final project uses primary data obtained from CV. Jeg Design and Soil Laboratory of Civil Engineering, Warmadewa University. The data obtained are:

Visual Data: This data is in the form of photographs of existing buildings, records of the physical condition of existing buildings and results of field measurements.

Material Data: Data on the quality of existing concrete and reinforcement, the results of material testing that has been carried out by CV Jeg Design.

Drawing Data as Built Drawing: Field measurement results that have been drawn by CV. Jeg Design.

Land Data: Soil data is in the form of sondir test results and Civil Engineering laboratory tests at Warmadewa University.

From the results of the data obtained, then proceed with making a structural analysis using ETABS software [15], which starts from modeling and examining the existing structure to strengthening.

3 Results and Discussion

3.1 Structure Modelling

The structural modeling using ETABS, as shown in Figure 2, provided a comprehensive understanding of the existing structure's behavior under various loading conditions. The three-dimensional model incorporated material properties including concrete strength of (f'c) 20.75 MPa, reinforcing steel grades BJTD 420 and BJTP 280, with consideration of the site's soil classification SE (Soft Soil). This baseline model was crucial for evaluating the structure's current capacity and determining necessary strengthening measures.

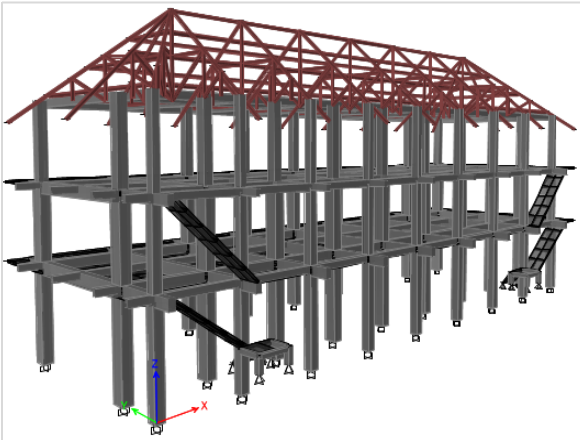

Figure 2. 3D Model of the Structures

3.2 Existing Deviation Examination

Based on SNI 1726:2019 Article 7.12.1 [16] the deviation between design levels (Δ), may not exceed the deviation between allowable levels (Δ_a) which is limited by Table 20. SNI 1726:2019.

Existing Structure Drift Analysis:

Deflection magnification factor, $C_d = 5.5$

Earthquake factor, $I_e = 1.5$ (Category IV)

Drift Limit:

$\Delta_a/\rho \quad = 0{,}010h/1{,}3$

$\quad\quad\quad = 0{,}007h$

Drift between floors:

$\Delta \quad = (\delta_{e\ atas} - \delta_{e\ bawah})C_d/I_e$

Displacement X-Dir (δ_{ex}):

1st floor move = 0 mm

2nd floor move = 6.949 mm

Beam Ring Displacement = 29.232 mm

Displacement Y-Dir (δ_{ey}):

1st floor move = 0 mm

2nd floor move = 10.869 mm

Beam Ring Displacement = 5.824 mm

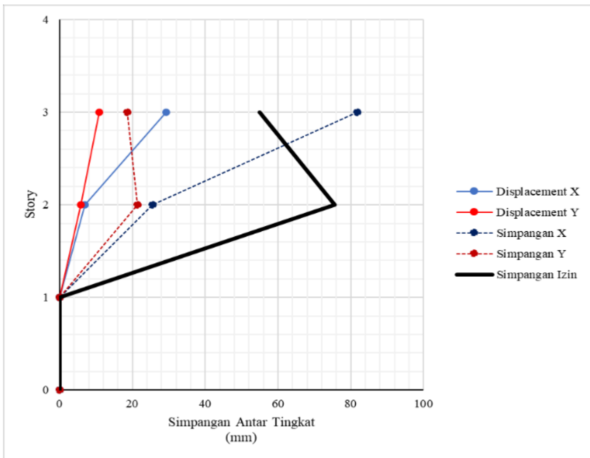

Figure 3. Existing Structure Deviations

The deviation analysis results presented in Figure 3 indicate significant structural vulnerability under lateral loading. Most concerning is the excessive drift in the X-direction (at roof level), which exceeds code-specified limits by approximately 40%. This excessive movement suggests inadequate lateral stiffness in the existing structure, which could lead to significant damage or potential collapse under design-level seismic forces. The Y-direction drift, while less severe, still indicates a need for comprehensive strengthening.

3.3 Strengthening Concrete Jacketing Beams

Based on the initial structural assessment and drift analysis, the existing beams required significant strengthening to meet the increased demands from the additional floor and to comply with current seismic codes. The design of the concrete jacketing for beams focused on both flexural and shear capacity enhancement, with careful consideration given to maintaining constructability and ensuring proper bond between existing and new concrete. The following calculations detail the strengthening design approach and verification:

Flexural Strength Analysis:

Deep style, Mu = -257.53 kNm

Number of top reinforcements, n = 6 bars

Rebar diameter, d_b = 22 mm

Provide reinforcement area = 2280.8 mm²

Effective cross-sectional height, d = 464 mm

Concrete block height, a

$$a \quad = \frac{As\ fy}{0{,}85\ f'c\ b} = 155{,}18\ \text{mm}$$

Nominal Flexural Strength:

$$M_n \quad = As\ fy\left(d - \frac{a}{2}\right) = 370{,}16$$

$\phi M_n = 0,9 \times 370,16 = 333,14 > Mu$, **OK**!

Shear Strength Analysis:

Deep style, Vu = 104.51 kN

Total stirrups, n = 2 units

Diameter of stirrup, d = 8 mm

Distance of stirrup, s = 200 mm

Area of the stirrups, Av = 257.61 mm^2

$$Vc = 0,17\lambda\sqrt{fc}\ b\ d = 132,54\ kN$$

$$Vs = \frac{Av\ fy\ d}{s} = 176,36\ kN$$

$$Vn = Vc + Vs = 308,9\ kN$$

$\phi Vn = 0,75 \times 308,9 = 231,67kN > Vu$, **OK**!

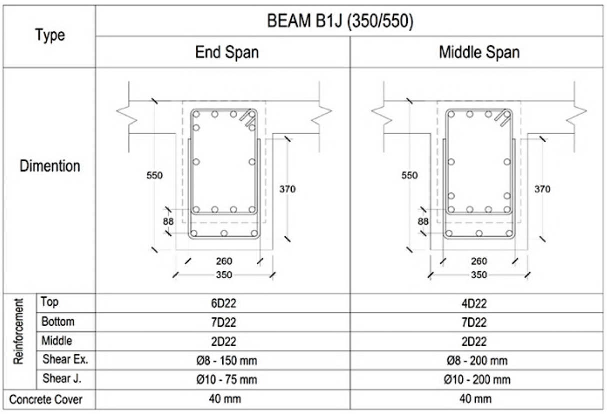

Figure 4. Concrete Jacketing Beams B1

The beam strengthening solution in Figure 4 shows a strategic approach to enhancing both flexural and shear capacity. The increase in beam B1's cross-section from 30×45 cm to 35×55 cm resulted in a 30% improvement in moment capacity, providing a substantial safety margin above the design demands. This enhancement was critical as these beams form the primary load path for gravity and seismic force.

3.4 Reinforcement of Concrete Jacketing Columns

Following the assessment of column capacity under combined axial and bending forces, it was determined that significant strengthening was required to ensure adequate performance under increased loading conditions. The following calculations verify the adequacy of the proposed jacketing solution:

Shear Capasity:

Mpr = 846,80 kNm

$$Vpr = \frac{2Mpr}{Ln} = 561,72\ kN$$

$$Vc = 0,17\left(1 + \frac{Nu}{14Ag}\right)\sqrt{fc}\ b\ d = 219,27\ kN$$

Existing Vs:

$$Vs = \frac{100,53 \times 280 \times 404,5}{100} = 113,86\ kN$$

Jacketing Vs:

$$Vs = \frac{226,2 \times 280 \times 404,5}{50} = 509,843\ kN$$

$$Vn = Vc + Vs = 841.32\ kN$$

$\phi Vn = 0,75 \times 841,32 = 630,99 > Vpr$, **OK**!

Check SCWB (Strong Column Weak Beam):

Mnc top column = 586.54kNm

Mnc lower column = 586.54kNm

Mnb pedestal on the beam = 372.07kNm

Mnb pedestal under the beam = 438.80 kNm

$\Sigma Mnc \geq 1,2\Sigma Mnb = 1173,08 > 973,04$, **OK**!

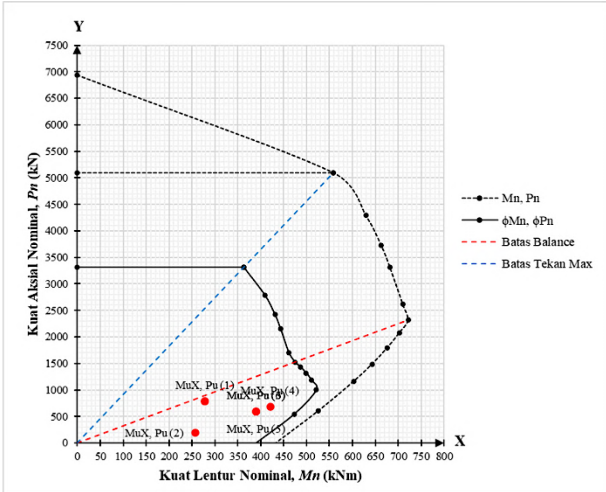

Figure 5. X-Direction K1 Column Interaction Diagram

Table 1. Force In Column K1

Condition	P_u (kN)	M_uX (kNm)	M_uY (kNm)
P_{max}	785,5234	278,2345	27,1093
P_{min}	194,1636	257,8266	35,6683
MX_{max}	594,7845	389,992	149,988
MX_{min}	690,1594	421,0783	95,2493
MY_{max}	594,7845	38,992	149,9988
MY_{min}	594,6212	389,9757	150,004

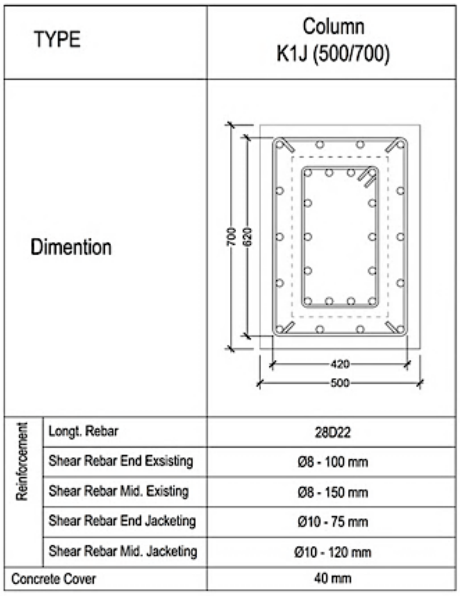

Figure 6. Concrete Jacketing Column K1

Column jacketing results (Figure 5 and Table 1) demonstrate a significant improvement in structural resilience. The enlarged K1 column section (50×70 cm) increased the axial load capacity by approximately 45% while substantially improving moment resistance. The interaction diagram in Figure 6 reveals that the strengthened columns operate well within their capacity envelope, with utilization ratios remaining below 80% under the most severe loading combinations. This improvement is particularly important for seismic resistance as it ensures adequate ductility under cyclic loading.

3.5 Post-Strengthening Performance

After implementation of the concrete jacketing system, a comprehensive analysis was performed to verify the effectiveness of the strengthening measures. This analysis was crucial to ensure that the strengthened structure could safely accommodate both the additional floor loads and meet seismic performance requirements. The results from ETABS modeling demonstrate significant improvements in structural behavior as detailed below:

Table 2. Elastic displacement

Story	Displacement (mm)		Elastic Drift (mm)		h (mm)
	δ_{eX}	δ_{eY}	δ_{eX}	δ_{eY}	
4	12.851	13.639	5.482	5.093	3600
3	7.369	8.546	3.918	4.461	3565
2	3.451	4.085	3.451	4.085	4916
1	0	0	0	0	0

Table 3. Allowable Interstory Drift

Story	Inter-Story Drift (mm)		Δa (mm)	Check Δ_X	Check Δ_Y
	Δ_X	Δ_Y			
4	20.101	18.674	27.692	OK!	OK!
3	14.366	16.357	27.423	OK!	OK!
2	12.654	14.978	37.815	OK!	OK!
1	0	0	0	-	-

The effectiveness of the strengthening scheme is clearly demonstrated in Table 2-3 and Figure 7. Story drifts were reduced by an average of 35% in both principal directions. This improvement is particularly significant given the planned addition of a third floor, as it indicates that the strengthened structure can safely accommodate the increased mass and loading demands while maintaining acceptable deformation levels. The interstory drift ratios now fall comfortably within code limits, with maximum values reaching only 85% of allowable thresholds.

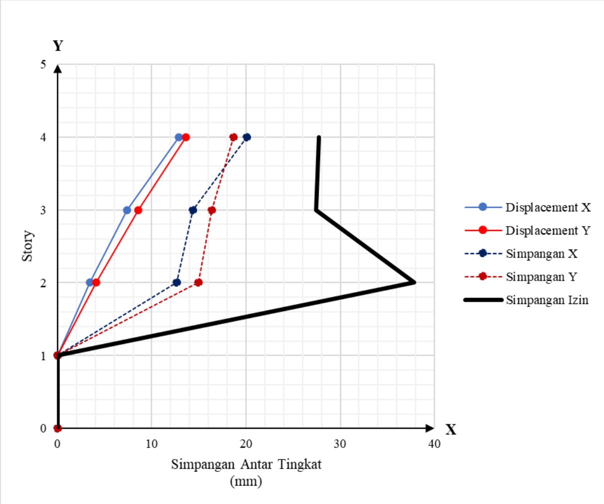

Figure 7. Strengthened Structure Deviations

3.6 Pilecap Strengthening

The addition of a floor and the increased column capacities from jacketing necessitated a careful evaluation and strengthening of the foundation system. The foundation design needed to address both the increased gravity loads and the modified seismic demands. Given the site's soft soil classification (SE), special attention was paid to ensuring adequate load transfer and preventing punching shear failure. The calculations below demonstrate the foundation strengthening design:

Pilecap Data:

Pile cap length, l = 2000 mm
Pilecap width, b = 2000 mm
Thick, t = 700
Reinforcement used = D13-150
Concrete quality, f'c = 20.75 MPa
Reinforcement quality, fy = 420 MPa
Concrete cover, cc = 75mm
Column length, c1 = 700 mm
Column width, c2 = 500
Effective thickness, d = 550mm
Critical cross-sectional width, B'1 = 1250mm
Critical cross-sectional width, B'2 = 1050 mm
Inner style, Pu = 611.78kN
The smallest axial, Nu = 1.14kN
Momen Ultimate, Mu = 257.19kNm
Pressure on the ground, σ = 81.07kN/m2
Concrete modification factor, λ = 1

One Way Shear Capacity:

Ag = 2000 × 2000 mm = 4×106 mm2

$Vc = 0{,}17\left(1 + \frac{Nu}{14Ag}\lambda\right)\sqrt{f'c}\,b\ d$

Vn = Vc = 851,83 kN

ϕVn = 0,75 × 851,83 = 638,87 kN > Pu, OK!

Two Way Shear Capacity:

$vc = 0{,}33\lambda\sqrt{f'c} = 1{,}55\ N/mm^2$

$vc, max = 0{,}17\lambda\sqrt{f'c} = 0{,}77\ N/mm^2$

$vc, pakai = 0{,}77 N/mm^2$

$vc, pakai = 774{,}38\ kN/m^2$

$vu_1 = \sigma(l^2 - B'1^2) = 197{,}60\ kN/m^2$

$vu_2 = \sigma(b^2 - B'2^2) = 234{,}89\ kN/m^2$

$\phi vc = 0{,}75 \times 774{,}38 = 580{,}79\ kN > vu, OK!$

Flexural Strength:

As $= 1769.76\ mm^2$

Concrete block, $a = \frac{As\ fy}{0{,}85\ f'c\ b} = 21{,}07\ mm$

Mn $= As\ fy\left(d - \frac{a}{2}\right) = 400{,}98\ kNm$

$\phi Mn = 0{,}9 \times 400{,}98 = 360{,}89\ kNm$

$\phi Mn > Mu, OK!$

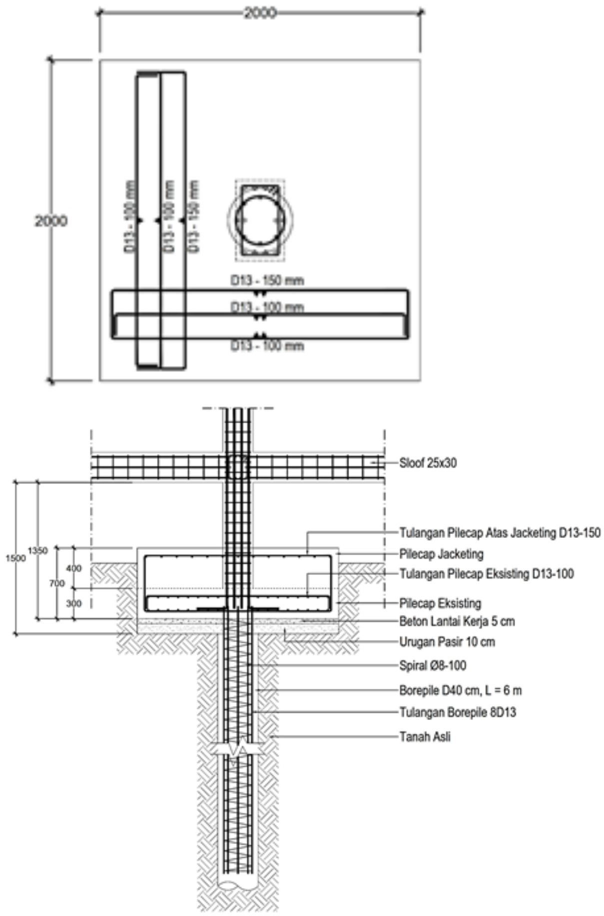

Figure 7. Pilecap Strengthening

The foundation strengthening design (Figure 7) addresses the increased demands from both the jacketing and additional floor. The 133% increase in pile cap thickness (from 300mm to 700mm) provides adequate punching shear resistance with a safety factor of 1.8, ensuring robust load transfer to the supporting soil. This substantial margin is crucial given the site's soft soil classification (SE) and the increased seismic demands on the foundation system.

4 Conclusion

Based on the results of the feasibility study and planning for additional floors using the concrete jacketing structure strengthening method for the South side of the Taruna Warmadewa Vocational High School building structure, it can be concluded as follows:

1. The existing B1E 30x50 beam with a 7.5m span was enlarged to become a 35x55 B1J beam. Existing beam B1E with a span of 4m, only provided with stirrup seals, without enlargement of the cross section. The existing B2E 20×30 beam was enlarged to become a 30×45 B2J beam.
2. The existing K1 30×50 column was enlarged to become the K1J 50×70 column. The existing K2 30×40 column was enlarged to become the K2J 45×45 column. The existing K3 25×25 column was enlarged to become the K3J 40×40 column.
3. Pilecap 300mm thick, thickened to 700mm with D13-150 top reinforcement.

This comprehensive strengthening solution not only remedies existing structural deficiencies but also creates a robust system capable of supporting the vertical expansion. The analysis results indicate that the concrete jacketing approach successfully transforms a vulnerable structure into one that meets or exceeds all current code requirements for both gravity and seismic loading conditions.

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