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The Effect of Choosing Slab Thickening or Adding Secondary Beams on the Cost of Reinforced Concrete Structures

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Abstract

In the implementation of structural work, structural component problems are often encountered. Some of these problems occur in the slab and beam components. This study aims to design floor slabs and beams for general spans in the field. The structural model analyzed is a 2-story school building located in the Jimbaran area, Nusa Dua. The floor slab is designed as a 2-way slab. The loading is adjusted to SNI 1727-2013 and the design of reinforced concrete structures is adjusted to SNI 2847-2012. From the planning results, the thickness of the slab without beams in general spans is 8x8 meters, which is 31 cm, 6x6 meters is 22 cm, 4x4 meters is 15 cm and 3x3 meters is 12 cm. While the thickness of the 12 cm plate is determined to produce the dimensions and number of beams in the general span, namely 8x8 meters, which is 25/50 cm, totaling 2 in the vertical direction, 6x6 meters, namely 20/35 cm in the vertical and horizontal directions, 4x4 meters in the 20/30 cm, one in the horizontal direction.

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1 Introduction

The construction industry in Indonesia has experienced rapid growth, particularly in building construction. This rapid development has led to an increasing demand for structural strengthening in buildings. During structural work, various problems related to structural components are frequently encountered, particularly in slabs and beams (Rios & Riera, 2004).

The thickness of a concrete slab is influenced by the maximum span of the structure. If the slab thickness is not appropriate for the maximum span, excessive vibration may occur. The minimum thickness of non-prestressed reinforced concrete slabs is regulated in the Requirements for Structural Concrete for Buildings (SNI 2847:2013), specifically in Section 9.5.3. In practice, the slab thickness is generally set at 12 cm for areas not exceeding 12 m² (Dewi, 2025).

2 Materials and Methods

This study employed a descriptive-experimental research design using structural modeling analysis of slabs and secondary beams. The analysis focused on slab deflection to determine the required slab thickness and the number of secondary beams for several typical spans, namely Ly = Lx, with dimensions of 3 m × 3 m, 4 m × 4 m, 6 m × 6 m, and 8 m × 8 m. The analysis was conducted to compare the costs required for slab thickening and the addition of secondary beams in reinforced concrete structures. The study used a school building located on Jalan Raya Kampus Udayana, Jalan Taman Ambengan No. 9, Jimbaran, as the case study. The research consisted of independent variables, population, and samples. The independent variables were slab thickness, secondary beams, and the calculation of the estimated construction cost. The population comprised all structural components of the school building used as the subject of the analysis, while the samples consisted of all or selected structural components of the building (Isufi & Ramos, 2021; Esfahani et al., 2007).

The structural analysis was performed using SAP2000 Version 14 based on the building data. The loading data referred to SNI 1727:2013 (Umum, 2007) and PPIUG 1983 (Ir Dwi Putranto Riau, 2019). The analysis was conducted based on the slab deflection requirements to control each dimension and determine whether it satisfied the applicable criteria. Reinforcement calculations were also performed for all structural components. The estimated construction cost was calculated after the structural drawings had been generated based on the completed structural analysis. The costs were then compared according to the alternatives of slab thickening or adding secondary beams (Santiana et al., 2024).

3 Results and Discussions

1. Calculation Results for Floor Slab Thickness

   An example calculation was selected for each alternative. The following parameters were assumed:
   - f'c = K-250 kg/cm² = 20.75 MPa
   - fy Ø = 240 MPa
   - fy D = 400 MPa
   - Modulus of elasticity of concrete:
     Ec = 4700 × √f'c = 21,410 MPa
   - Modulus of elasticity of steel: Es = 200,000 MPa

The floor slab thickness was initially determined as 150 mm
For a slab span of Ly = Lx = 4000 × 4000 mm.

$$\frac{Ly}{Lx} = \frac{4000}{4000} = 1$$

Therefore, it is designated as a two-way slab, 1 < 2,5.
The span ratio was calculated as follows: $L_y/L_x = 4000/4000 = 1$
Therefore, the slab was classified as a two-way slab, since the ratio satisfies $1 < L_y/L_x < 2.5$.

1. **Maximum Slab Deflection Control Analysis**

The entire structural modeling process was performed using the following calculation method to evaluate the maximum slab deflection.
The allowable maximum deflection was determined as:
$L_x/240 = 4000/240 = 16.6667$ mm
The gross moment of inertia of the slab section was calculated as:
$I_g = 1/12 \times b \times h^3 = 281{,}250{,}000$ mm^4
The modulus of rupture of concrete was calculated as:
$f_r = 0.7 \times \sqrt{f'c} = 3.1887$ MPa
The ratio of the modulus of elasticity was:
$n = E_s/E_c = 200{,}000/21{,}410 = 9.81$
The neutral axis distance from the top surface of the concrete was calculated as:
$c = n \times A_s/b = 6.5097$ mm
The cracked-section moment of inertia was then calculated as:
$I_{cr} = (1/3 \times b \times c^3) + [n \times A_s \times (d - c)^2] = 281{,}250{,}000$ mm^4
The distance from the centroidal axis to the extreme tension fiber was:
$y_t = h/2 = 75$ mm
The cracking moment of the concrete section was calculated as:
$M_{cr} = f_r \times I_g/y_t = 11{,}957{,}444$ Nmm
The maximum moment due to unfactored loading was:
$M_a = 1/8 \times Q \times L_x^2 = 14{,}100{,}000$ Nmm
The effective moment of inertia for deflection analysis was then determined using:
$I_e = (M_{cr}/M_a)^3 \times I_g + [1 - (M_{cr}/M_a)^3] \times I_{cr}$
The resulting effective moment of inertia was:
$I_e = 203{,}419{,}007$ mm^4
The short-term elastic deflection due to dead and live loads was calculated as:
$\delta = 5/384 \times Q \times L_x^4/(E_c \times I_e) = 5.39597$ mm
The allowable deflection requirement was:
$\delta_{allow} = L_x/240 = 16.6667$ mm
Since the calculated deflection was 5.39597 mm < 16.6667 mm, the slab satisfied the allowable deflection requirement. Therefore, based on the deflection control analysis, a 150 mm thick floor slab was adopted.

2. **Slab Loading Analysis**

Based on the results of the slab deflection control analysis, the next stage involved developing a structural model using SAP2000 Version 14. The model incorporated dead loads and live loads in accordance with SNI 1727:2013 and PPIUG 1983.
Dead Load
The dead load of the floor slab was calculated based on the self-weight of the slab and the floor finishing load.
Self-weight of floor slab:
Weight of floor slab = Unit weight of concrete × Slab thickness
= 24 × 0.15
= 3.6 kN/m²
Floor finishing load:
Floor finishing load = Unit weight of concrete × Finishing thickness

Floor finishing load (kN/m2):
= 22 × 0.05
= 1.10 kN/m²
Ceiling and frame load:
= 0.18 kN/m²

MEP installation load:
= 0.25 kN/m²
Therefore, the total dead load (QD) is:
QD = 3.60 + 1.10 + 0.18 + 0.25 = 5.13 kN/m²
Live Load
The live load for classroom areas was determined based on SNI 1727:2013:
Live load = 1.92 kN/m²
Calculation of Factored Design Load
Qu = 1.2 x QD + 1.6 x QL
Qu = 1.2 x 11.13 + 1.6 x 1.92 =9,228 kN/m2

Table 1
Live Load

No.	Use / Application	Uniform Load (kN/m²)	Concentrated Load (kN)
1	Dining and restaurant areas	4.79	–
2	Roof		
	– Flat, pitched, and curved roofs	0.96	–
3	Storage and work areas		
	– Weight	11.97	–
4	Stairs and exits	4.79	1.33
5	Garage / Parking		
	– Passenger vehicles	1.92	–

Source : SNI 1727-2013

3. **Load Combination**
The load combination used in this analysis only considered the factored dead load and live load. The second load combination, which consists of dead load and live load, was applied using the following equation:
Load Combination = 1.2 × DL + 1.6 × LL

4. **SAP2000 Analysis Results – Stage 1**
The results of the structural analysis using the slab thickening alternative are presented below. The analysis was performed using SAP2000 Version 14, based on the input data and calculations that had been previously determined.

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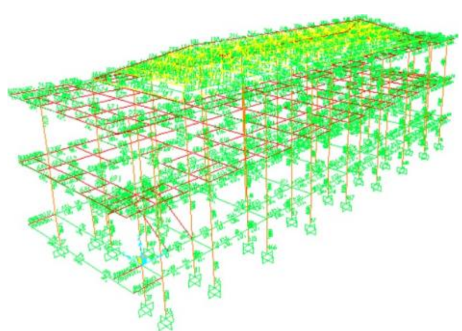
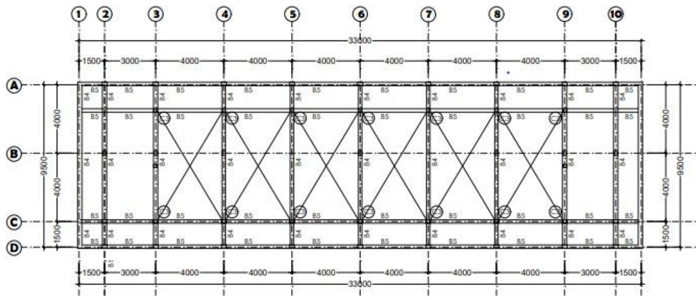


Picture 1. Output SAP 2000

Once the structural modeling was completed, the next stage involved preparing the structural floor plan and structural detail drawings. The following figure presents one of the structural drawings generated from the SAP2000 Version 14 analysis.



Picture 2. Beam Layout

Based on the structural analysis using SAP2000 and the manual slab calculations, particularly the slab deflection requirements, the appropriate slab thicknesses for each of the previously analyzed typical spans were determined. The calculated slab thicknesses were found to satisfy the allowable deflection requirements. For a 4 m × 4 m span, the slab thickness that satisfies the allowable deflection requirement was determined to be 15 cm (150 mm).

5. SAP2000 Analysis Results – Stage 2

The results of the structural analysis using the secondary beam addition alternative are presented below. The analysis was conducted based on the input data and calculations that had been previously determined

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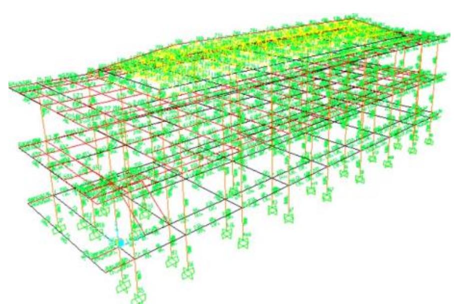
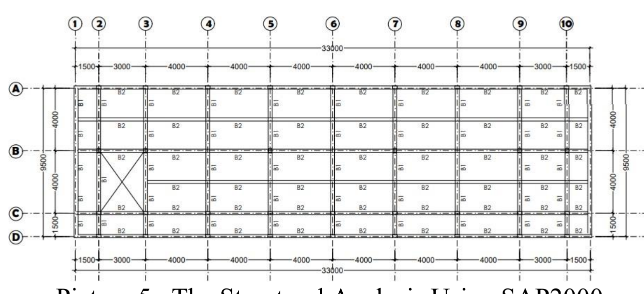


Picture 3. Output SAP 2000



Picture 5. The Structural Analysis Using SAP2000

Based on the structural analysis using SAP2000 and the manual slab calculations, particularly the slab deflection requirements, the appropriate slab thicknesses for each of the previously analyzed typical spans were determined. The calculated thicknesses were found to satisfy the allowable deflection requirements. For a 4 m × 4 m span, the slab thickness that satisfies the allowable deflection requirement was determined to be 12 cm

(120 mm), with the addition of one secondary beam measuring 200 × 300 mm, oriented in the horizontal direction.

6. Analysis of the Estimated Construction Cost

The following section presents the unit price analysis for each structural work item.

Table 2
Analysis of Concrete Work Costs

NO.	JOB DESCRIPTION	SAT.	COEFFICIENT		UNIT PRICE		QTY PRICE
1.	Unit Price Qty Price f'c = 21,7 Mpa (K.250), slump (12 ± 2)						
A	POWER						
	Worker	OH	1,65	Rp	95.000,00	Rp	156.750,00
	Mason	OH	0,275	Rp	110.000,00	Rp	30.250,00
	Head Mason	OH	0,0275	Rp	110.000,00	Rp	3.025,00
	Foreman	OH	0,083	Rp	120.000,00	Rp	9.960,00
			NUMBER OF WORKERS			Rp	199.985,00
B	MATERIALS						
	Portland Cement	Kg	384	Rp	1.380,00	Rp	529.920,00
	Concrete Sand	Kg	692	Rp	164,11	Rp	113.562,14
	Gravel (Max 30 mm)	Kg	1039	Rp	207,30	Rp	215.380,85
	Water	Liter	215	Rp	42,00	Rp	9.030,00
			TOTAL COST OF MATERIALS			Rp	867.892,99
C	EQUIPMENT						
			TOTAL COST OF EQUIPMENT			Rp	-
D	Total (A+B+C)					Rp	1.067.877,99
E	Overhead & Profit		0,1			Rp	106.787,80
F	Unit Price of Work (D+E)					Rp	1.174.665,79

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Table 3
Price Analysis for Rebar Work

NO.	JOB DESCRIPTION	SAT.	COEFFICIENT	UNIT PRICE		QUANTIY PRICE	
2. Reinforcement work (10 kg) using plain or deformed bars.A							
A	POWER						
	Worker	OH	0,07	Rp	95.000,00	Rp	6.650,00
	Mason	OH	0,07	Rp	110.000,00	Rp	7.700,00
	Head Mason	OH	0,007	Rp	110.000,00	Rp	770,00
	Foreman	OH	0,004	Rp	120.000,00	Rp	480,00
			NUMBER OF WORKERS			Rp	15.600,00
B	BAHAN						
	Concrete Reinforcing Bar (plain/deformed)	kg	10,5	Rp	11.000,00	Rp	115.500,00
	Binding Wire	kg	0,15	Rp	19.443,00	Rp	2.916,45
			COST MATERIAL TOTAL			Rp	118.416,45
C	EQUIPMENT						
			TOTAL COST OF EQUIPMENT			Rp	-
D	Total (A+B+C)					Rp	134.016,45
E	Overhead & Profit		0,1			Rp	13.401,65
F	Unit Price of Work (D+E)					Rp	147.418,10

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Tabel 4
Formwork Work Cost Analysis

NO.	JOB DESCRIPTION	SAT.	COEFFICIENT		UNIT PRICE		QUANTITY PRICE
2.	Installation of 1 m² of formwork for columns						
A	POWER						
	Worker	OH	0,66	Rp	95.000,00	Rp	62.700,00
	Mason	OH	0,33	Rp	110.000,00	Rp	36.300,00
	Head Mason	OH	0,033	Rp	110.000,00	Rp	3.630,00
	Foreman	OH	0,033	Rp	120.000,00	Rp	3.960,00
			NUMBER OF WORKERS			Rp	106.590,00
B	MATERIALS						
	Class III Timber	m3	0,04	Rp	4.130.188,00	Rp	165.207,52
	5–12 cm Nails	Kg	0,4	Rp	14.500,00	Rp	5.800,00
	Formwork Oil	Liter	0,2	Rp	17.250,00	Rp	3.450,00
	Class II Timber Beams	m3	0,015	Rp	4.130.188,00	Rp	61.952,82
	9 mm Thick Plywood	Lbr	0,35	Rp	134.760,00	Rp	47.166,00
	Galam wood piles ø 8-10cm with long 4 m	Batang	2	Rp	25.750,00	Rp	51.500,00
			TOTAL COST OF MATERIALS			Rp	335.076,34
C	EQUIPMENT						
			TOTAL COST OF EQUIPMENT			-	
D	Total (A+B+C)					Rp	441.666,34
E	Overhead & Profit		0,1			Rp	44.166,63
F	Unit Price of Work (D+E)					Rp	485.832,97

Each of the unit price analyses above will be multiplied by the work volume for each alternative. The resulting cost estimates for each alternative are presented in a comprehensive summary.

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Tabel 5
Cost Summary for Each Alternative

NO.	JOB DESCRIPTION	TOTAL PRICE (Rp.)
A.	8 M X 8 M SPAN	
1.	STRUCTURAL WORK ALTERNATIVE THICKNESSING SLAB	1.404.121.083,00
2.	STRUCTURAL WORKS ADDITIONAL ALTERNATIVES BUILDING SMALL BLOCKS	1.015.840.587,00
B.	6 M X 6 M SPAN STRUCTURAL WORK	
1.	ALTERNATIVE THICKNESSING PELAT	1.039.243.800,00
2.	STRUCTURAL WORKS ADDITIONAL ALTERNATIVES BUILDING SMALL BLOCKS	922.559.114,00
C.	4 M X 4 M SPAN STRUCTURAL WORK	
1.	ALTERNATIVE THICKNESSING PELAT	1.368.727.913,00
2.	STRUCTURAL WORKS ADDITIONAL ALTERNATIVES BALOK ANAK	1.393.379.346,00
D.	3 m x 3 m SPAN	
1.	STRUCTURAL WORK ALTERNATIVE THICKNESSING PELAT	5.876.322.583,00

4 Conclusion

Based on the explanation above, it can be concluded that :

a) For the 8m x 8m span, a slab thickness of 31 cm was determined to satisfy deflection requirements without the use of secondary beams; for the 6m x 6m span, the required thickness was 22 cm; for the 4m x 4m span, it was 15 cm; and for the smallest span studied (3m x 3m), the required thickness was 12 cm.

b) In the second alternative—involving the addition of beams—the following specifications were determined: for the 8m x 8m span, two secondary beams with dimensions of 250/500 mm; for the 6m x 6m span, one secondary beam of 200/350 mm and one of 200/300 mm; and for the 4m x 4m span, one secondary beam of 200/300 mm. For the smallest span studied (3m x 3m), no secondary beam was required, as the slab had already reached the minimum thickness necessary to satisfy deflection criteria at 12 cm.

c) Regarding total costs: for the 8m x 8m span, the cost was Rp 1,404,121,083.00 when relying on increased slab thickness, whereas the cost was Rp 1,015,840,587.00 when adding secondary beams. For the 6m x 6m span, the cost was Rp 1,039,243,800.00 with increased slab thickness, compared to Rp 922,559,114.00 with secondary beams. For the 4m x 4m span, the cost with increased slab thickness was Rp..1,368,727,913.00, whereas the cost for adding secondary beams was found to be Rp 1,393,379,346.00. Based on the calculated volumes, it can be concluded that slab thickening incurs a higher cost than adding secondary beams. However, for the 4-meter x 4-meter span, slab thickening proved to be the more efficient alternative. Thus, while adding secondary beams is more efficient than slab thickening for 8-meter x 8-meter and 6-meter x 6-meter spans, slab thickening is more efficient for the 4-meter x 4-meter span.

Conflict of interest statement
The authors declared that they have no competing interest.

Statement of authorship
The authors have a responsibility for the conception and design of the study. The authors have approved the final article.

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