Analysis of Formwork Requirements for Reinforced Concrete Beams and Slabs in Building Construction Projects

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Abstract. Formwork is a critical component of reinforced concrete construction that affects structural quality, construction efficiency, and project costs. This study aims to analyze the material requirements and costs of formwork for reinforced concrete beams and slabs in a two-story healthcare facility construction project. The research method used is quantitative descriptive, involving the calculation of formwork area based on working drawings, followed by an analysis of material requirements and the costs of formwork construction. The results of the study show that the total area of formwork required for the beams and slabs is 670.67 m². Based on this area, the material requirements are 466 sheets of plywood, 135 kg of nails, and 84 liters of formwork oil, with respective costs of Rp139,800,000, Rp3,780,000, and Rp2,520,000. Additionally, the formwork work requires equipment rental for six months at a cost of Rp44,506,000 per month, bringing the total rental cost to Rp267,036,000. The subcontractor cost for the 670.67 m² formwork work is Rp167,689,000. The total cost of formwork work, including materials, equipment rental, and subcontractor costs, is Rp580,825,000. Based on the analysis, the costs of renting equipment and purchasing plywood are the largest cost components in formwork operations. Therefore, optimizing the use of formwork materials and equipment can help improve the cost efficiency of construction projects.

Introduction

The construction of high-rise buildings in Indonesia continues to grow in line with the demand for residential, office, and educational facilities, as well as other supporting infrastructure. Reinforced concrete work is a critical phase in the execution of building construction projects. The success of structural work depends not only on the quality of the concrete and reinforcement, but also on the formwork system used. Formwork serves as a temporary mold that supports the fresh concrete until it reaches sufficient strength to support its own weight[1]. In reinforced concrete beam-and-slab construction, formwork accounts for a significant portion of the work compared with other structural elements. Errors in planning formwork requirements can lead to material waste, project delays, and even temporary structural failure, compromising project safety[2].

However, cost-saving measures not based on adequate technical calculations can cause formwork failure. Reducing the number of supports, using formwork materials that do not meet specifications, spacing supports beyond design requirements, or accelerating the pouring process without considering the formwork's capacity can lead to the collapse of temporary structures during construction. Formwork failure not only results in material losses and project delays but can also lead to workplace accidents that endanger worker safety[3]. A common formwork failure found in construction is the collapse of shoring and formwork systems due to inadequate design or installation of supports. Many concrete structural failures during the construction phase begin with local failures in support elements or formwork, which then progress into progressive collapse over a wider area. These conditions are generally triggered by design errors, construction errors, or the omission of support elements that should have been installed according to the design. The investigation concluded that the partial collapse of the building occurred because the temporary shoring system installed was inadequate during the structural repair process. The collapse could have been prevented if an appropriate shoring plan and construction phasing had been implemented. Reducing or under-specifying the temporary shoring system for the sake of cost efficiency can have serious consequences for safety and the project's viability.

The formwork installation method must also be planned to ensure that installation, pouring, and dismantling proceed according to the project schedule. Choosing the right method will affect work productivity, the quality of the concrete pour, and the efficient use of project resources[4]. Advances in construction technology have led to the development of various formwork systems; optimizing formwork planning can improve the efficiency of material and resource use during the construction process. Controlling formwork material requirements can impact costs, construction time, work quality, and construction safety.

The standard spacing used for beam and slab supports in building construction is 1 m to 1.2 m for beam heights of 30 cm to 50 cm, 0.8 m to 1 m for beam heights of 50 cm to 70 cm, and 0.6 m to 0.8 m for beam heights of 70 cm to 1 m. These calculations require further review; in this study, only the applicable standards and spacing were used[5].

Based on the above description, this study is necessary to determine the formwork requirements that align with the structural design and to evaluate the construction methods applied to the project. Thus, the objective of this study is to determine the volume and material requirements for the formwork to be used, as well as to analyze the impact of implementing methods that are safe and appropriate yet cost-effective. The study is also expected to serve as a reference for the planning and execution of safe, effective, and economical formwork work, thereby minimizing the risk of construction failure due to calculation errors or inappropriate cost-cutting measures.

Research Methodology

The subject of this study is the formwork work involved in the construction of a building for the provision of health care facilities for public health services (UKM) and individual health services (UKP) in a regency in Central Kalimantan Province. The building under study is a two-story health service facility designed to support primary health care, including examination rooms, general clinics, dental clinics, procedure rooms, a pharmacy, and other supporting facilities. This health facility serves as a venue for implementing UKM and UKP, which aim to improve public health through promotive, preventive, curative, and rehabilitative services.

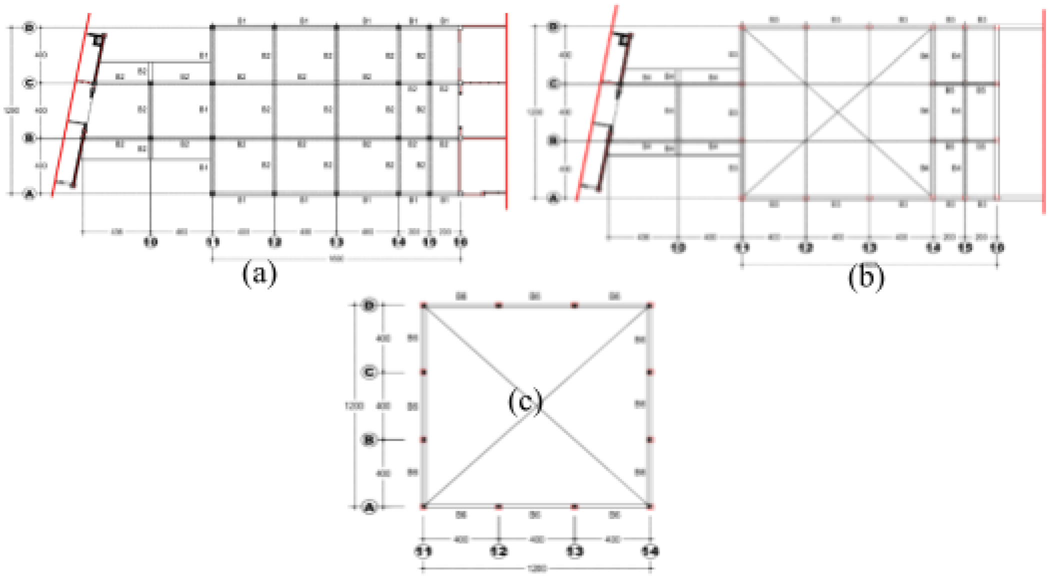


Fig.1 Construction plan for beams and slabs (a) Floor plan elv.+4 m (b) Floor plan elv.+7,2 m (c) Floor plan elv.+8,4 m

In the formwork for reinforced concrete beams and slabs, material requirements and cost calculations are performed systematically to determine the amount of material needed and to estimate the cost of the work[6]. The calculation steps are as follows:

1. Gather design data such as working drawings, beam and slab dimensions, material specifications and prices, and labor rates.
2. Calculate the formwork area for beams, where L_b is the formwork area, h is the beam height, b is the beam width, and p is the beam length

   $$L_b = (2\ h + b) \times p \tag{1}$$
3. Calculate the formwork area for slabs, where L_p is the formwork area, p and l are the slab length and width

   $$L_p = p \times l \tag{2}$$
4. Calculate the total formwork volume required

   $$L_t = L_b \times L_p \tag{3}$$
5. Calculate material requirements, Materials needed may include plywood, oil and others.
6. Calculate the equipment requirements needed to support the temporary load of fresh concrete. Support equipment may include shoring, scaffolding, bracing, and other equipment
7. Calculate material and labor costs, This can be referred to as a unit price analysis

   $$\text{material costs} = \text{volume} \times \text{unit price for the work} \tag{4}$$
8. Analyze the results of the calculations and draw conclusions

Result and Discussion

When calculating the formwork requirements for reinforced concrete beams and slabs, technical specifications for the work are needed as the basis for analysis to ensure that the calculation results align with on-site conditions. These specifications include the type and thickness of plywood, the dimensions and type of support beams, the spacing between supports, the formwork system used, and the formwork installation standards applied to the project. Calculating formwork requirements also requires structural dimensions. The dimensions required for this calculation are as follows:

Table.1 List of beam and plate dimensions

No	Description	Height (m)	Width (m)
1	Type B1 for Beam	0.45	0.30
2	Type B2 for Beam	0.45	0.25
3	Type B3 for Beam	0.35	0.30
4	Type B4 for Beam	0.35	0.25
5	Type B5 for Beam	0.30	0.20
6	Type B6 for Beam	0.25	0.20
7	Plate thickness	0.13	

Volume or area calculations for beam and slab formwork are performed to determine the material requirements for the project. These calculations are based on the surface area of the concrete that comes into direct contact with the formwork. For beam formwork, the area is calculated from the two sides and the bottom of the beam, while for slab formwork, it is calculated based on the area of the slab's underside that requires formwork during the pouring process. The results of these formwork volume calculations are then used as a basis for determining material requirements such as plywood, hollow sections, and scaffolding, as well as for estimating project costs. The following are the volume calculations:

Table. 2 Calculating the volume of beams and slabs

No	Description		Height (m)	Width (m)	length	Volume
1	Type B1 for Beam	elv. +4 m	0.45	0.30	44.00	52.80
2	Type B2 for Beam	elv. +4 m	0.45	0.25	104.36	120.01
3	Type B3 for Beam	elv. +7.2 m	0.35	0.30	44.00	44.00
4	Type B4 for Beam	elv. +7.2 m	0.35	0.25	48.36	45.94
5	Type B5 for Beam	elv. +7.2 m	0.30	0.20	8.00	6.40
6	Type B6 for Beam	elv. +8.4 m	0.25	0.20	48.00	33.60
7	Plate thickness	elv. +4 m		16.00	12.00	192.00
	Plate thickness	elv. +4 m		8.00	8.00	64.00
8	Plate thickness	elv. +7.2 m		12.00	4.00	48.00
	Plate thickness	elv. +7.2 m		8.00	8.00	64.00

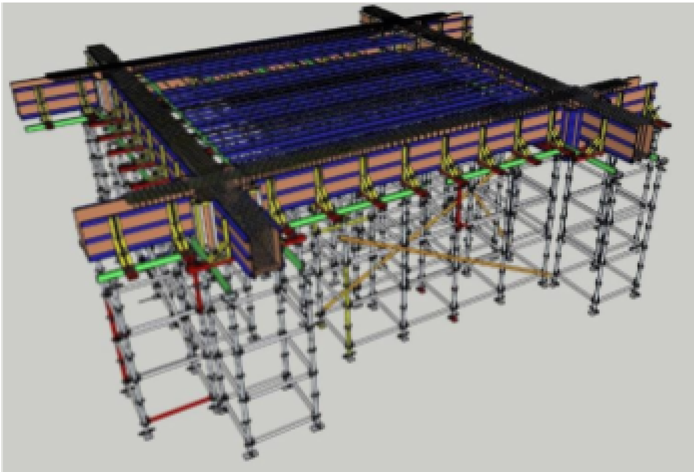
The calculation of the required plywood for two uses, as well as nails and formwork oil, can be done as follows:

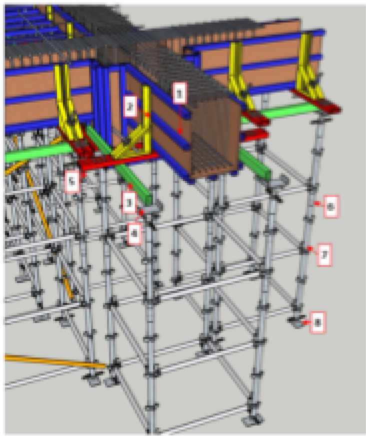
$$Plywood\ sheet\ = \frac{formwork\ area}{plywood\ area\ x\ total\ usage} = \frac{670{,}76}{(1{,}2x2{,}4)x2} = 465{,}803 \approx 466\ \text{sheet}$$

Weight of nail = formwork area x coefficient = 670,76 x 0,3 = 134,15 $\approx$ 135 kg

$$oil\ volume\ = \frac{formwork\ area}{average\ requirement} = \frac{670{,}76}{8} = 83{,}84 \approx 84\ \text{litter}$$

As a note, the nail coefficient can range from 0.1 to 0.3 kg/m², and the average requirement for formwork oil is 1 liter per 8 m². Next is the calculation of the equipment used to support the formwork. It is best to present this visually to illustrate the installation process and to serve as supporting documentation for the work execution method. The visual representation and details of the equipment used are as follows:





No	Description
1	Hollow 40/60 p=6m; p=2 m
2	Beam clamp
3	Coloumn Hollow 50/70
4	U-head
5	Girder
6	PCH vertical/ PCH Horizontal
7	Wing nut
8	Jack base

Fig.2 formwork equipment and visual guide to use

The use of formwork equipment for a single work zone and the estimated cost of renting the equipment for one month of work are as follows

Table 3. Equipment details and rental estimates

No	Description	Volume		Price	Total Price
1	Hollow 40/60 p=6m	56	unit	30,000.00	1,680,000.00
2	Hollow 40/60 p=2 m	35	unit	10,000.00	350,000.00
3	Beam clamp	462	unit	7,000.00	3,234,000.00
4	Coloumn Hollow 50/70	126	unit	40,000.00	5,040,000.00
5	U-head	154	unit	8,000.00	1,232,000.00
6	Girder	77	unit	50,000.00	3,850,000.00
7	PCH vertical (1 m)	1120	unit	15,000.00	16,800,000.00
8	PCH Horizontal (1 m)	672	unit	15,000.00	10,080,000.00
9	Wing nut	672	unit	1,500.00	1,008,000.00
10	Jack base	154	unit	8,000.00	1,232,000.00
11	Total Price				44,506,000.00

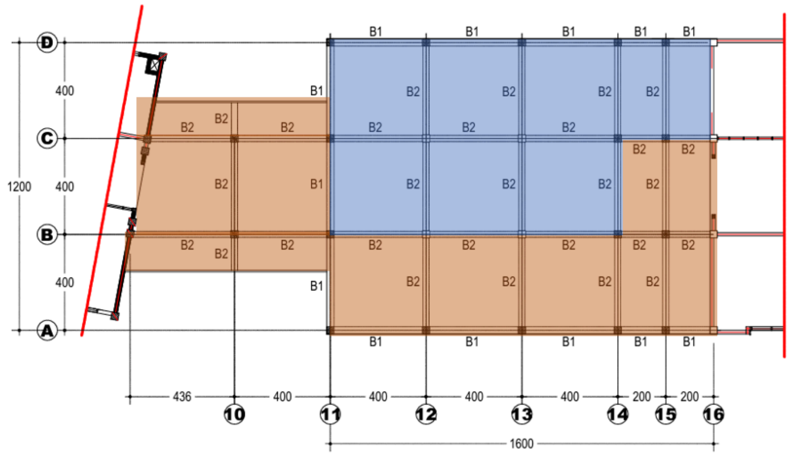


Fig.2 division of work zones

If the work zone is divided into two sections, with the duration of formwork use calculated as 10 days prior to concrete pouring (for the assembly and installation of reinforcing bars), 28 days for the concrete to reach its compressive strength, and 5 days for dismantling, the total duration of work for one zone is 43 calendar days. Since the entire building is divided into 4 zones, the total duration of the work or formwork equipment usage is 172 calendar days, or approximately 6 months. For the purposes of this study, labor costs are assumed to be incurred through a subcontractor at a rate of Rp 250,000, using a formwork system consisting of semi-aluminum formwork. The total cost of the formwork is as follows:

Table 4. cost of formwork for beams and slabs

No	Desription	Volume		Price	Total Price
1	Plywood	466.00	sheet	300,000.00	139,800,000.00
2	Nail	135.00	kg	28,000.00	3,780,000.00
3	Oil for formwork	84.00	litter	30,000.00	2,520,000.00
4	formwork equipment	6.00	monthly	44,506,000.00	267,036,000.00
5	labor costs for formwork subc	670.76	m2	250,000.00	167,689,000.00
6	Total Price				580,825,000.00

Conclusion

Based on the results of the analysis of formwork requirements for reinforced concrete beams and slabs in a building construction project, the total formwork area was determined to be 670.67 m². Based on this area, the required formwork materials include 466 sheets of plywood, 135 kg of nails, and 84 liters of formwork oil, with total costs of Rp139,800,000, Rp3,780,000, and Rp2,520,000, respectively. These calculations show that plywood is the primary material with the largest cost contribution in the formwork work.

In addition to material costs, the formwork work also requires supporting equipment that is rented for 6 months at a rental cost of Rp44,506,000 per month, bringing the total equipment rental cost to Rp267,036,000. For the execution of formwork work covering an area of 670.67 m², the required subcontractor cost is Rp167,689,000. Taking into account all cost components—namely materials, equipment rental, and subcontractor costs—the total cost of the formwork work amounts to Rp580,825,000. The results of this study indicate that equipment rental costs and the procurement of plywood are the most dominant cost components in formwork work.

For future research, it is recommended to compare conventional formwork systems with modern formwork systems, such as aluminum formwork or modular formwork, to determine the most cost- and time-efficient method. Additionally, the research can be expanded by considering the reuse factor of formwork materials, labor productivity, and the use of technologies such as Building

Information Modeling (BIM) to improve the accuracy of material requirement calculations and control formwork project costs.

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