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Evaluation of the Effectiveness of Using Wood in Building Formwork Construction †

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Abstract

The use of formwork in construction is crucial as structural support, and its success depends on proper design and calculations that meet standards and economic efficiency. This study analyzes formwork in the G building project. For plywood, Mu, Vu, and deflection (δ) are safe but inefficient due to high safety factors. In the first support beam, Mu and δ are safe and very efficient, while Vu is safe but inefficient. In the second support beam, Mu and Vu are safe and efficient, but δ is safe yet inefficient. Therefore, proper technical data and strength analysis are needed for optimal implementation.

Keywords: formwork; meranti wood; pine wood; load bearing; efficiency

1. Introduction

Formwork is a crucial supporting structure in concrete construction [1]. Formwork itself is used as a mold to shape the concrete and also as a support for the concrete itself [2]. There are two types of formwork, namely modern formwork made of iron and conventional formwork made of wood [3]. The types of formwork are more clearly shown in (Figure 1).



(**a**) (**b**)

Figure 1. (**a**) Modern formwork using iron and wood, (**b**) Conventional formwork.

In terms of cost, the use of semi-modern formwork is more efficient than using wooden formwork in terms of building area and number of floors [4]. According to Perwitasari, et. al., modern formwork is superior to conventional formwork because modern formwork uses durable materials [5,6]. In addition, it can be used repeatedly, thereby saving costs [7].

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The types of wood used for formwork construction are meranti and pine. Meranti wood (*Shorea leprosula* Miq.) is a type of wood commonly used for housing, shipping, and furniture [8]. Meanwhile, pine wood (*Pinus Merkusii*) is a type of wood commonly used as furniture material and also has a high level of resistance to fungi [9].

A project is an activity aimed at achieving a specific end result for all parties involved [10]. In a project, it is often found that the construction contractor does not use technical rules (structural calculations) and only relies on previous work experience [11–13]. This has an impact on the uncertainty of the construction work in terms of both safety and efficiency [14,15]. The possible consequences of this construction are, first, unsafe construction, which can even lead to a risk of structural collapse [16]. Second, the construction may be safe and efficient, or safe but inefficient due to the excessive use of materials [17].

This paper analyzes the use of formwork construction materials in the construction project of the G Jenderal Sudirman building at the University of Muhammadiyah Kalimantan Timur. Observations of this project revealed that there was no analysis of formwork calculations for the installation of formwork construction, only working drawings.

2. Research Method

This paper is based on observations and field surveys in the form of construction data compiled into models, which were then used to create detailed technical drawings of formwork construction. Analysis was then conducted to determine the efficiency of formwork timber usage. This is illustrated in more detail in Figure 2 below.

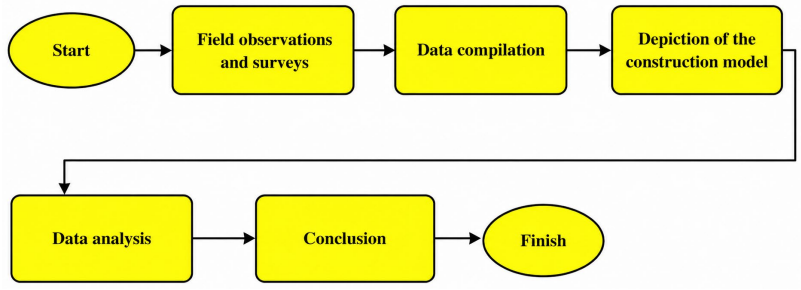


Figure 2. Research flow chart.

As seen in the flow chart of the above method, (Figure 2) the research begins with observation to complete the data and a direct survey in the field. Then, after the data has been obtained, it is combined from the data that has been collected and the image is redrawn. The combined data is then analyzed to see whether the material efficiency is wasteful or not.

To determine the efficiency of this formwork construction, criteria based on safety factor values are used, which are divided into several conditions as shown in Table 1 below.

$$\text{Efficiency Value, EV} = \frac{\text{Conditions}}{\text{Values that occur}} \quad (1)$$

Table 1. Construction efficiency criteria.

Efficiency Value (EV)	Condition
$0 < EV < 1$	Unsafe and inefficient
$1 < EV < 2$	Safe and highly efficient
$2 < EV < 3$	Safe and efficient
$3 < EV < 4$	Safe and less efficient
$EV > 4$	Safe and inefficient

3. Results and Discussion

In the formwork installation, there is a load flow mechanism that is supported by plywood formwork, support beams, support timbers, and scaffolding (continued to the foundation) as shown in Figure 3, the load flow analysis flowchart below.

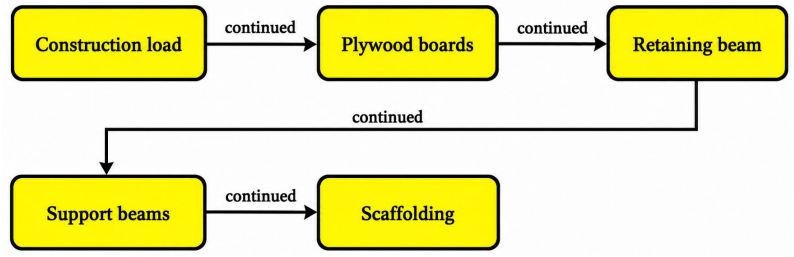
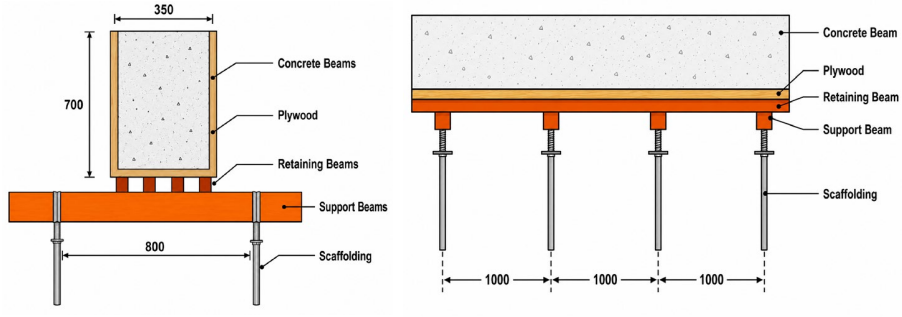


Figure 3. Load flow analysis flow chart.

The following technical data on materials and construction drawings use millimeters as the unit of measurement, as shown in Figure 4 below.



(**a**) (**b**)

Figure 4. (**a**) The top image shows a detailed cross-section of the formwork structure, while the bottom image (**b**) shows a detailed side view. (Source: researcher).

3.1. Analysis of Plywood Formwork

The loads acting on the plywood are its own weight, the weight of wet concrete, casting equipment, and workers.

The weight of reinforced concrete according to SNI 2847-2013 is 2400 kg/m^3, therefore [18]:

Concrete Beam Dimensions

$$b = 0.35 \text{ m}$$
$$h = 0.70 \text{ m}$$

In this project, pine wood is used for the plywood formwork with the following material data and plywood dimensions.

$$\begin{aligned} &\text{Flexural strength (Fb)} && = 20 \text{ MPa} \\ &\text{Shear strength (Fv)} && = 4.5 \text{ MPa} \\ &\text{Tensile strength parallel to grain (ft)} && = 19 \text{ MPa} \\ &\text{Compressive strength parallel to grain (fc)} && = 25 \text{ MPa} \end{aligned}$$

Corrected flexural strength

$$\begin{aligned} Fb' &= 0.8 \times 20 \\ &= 16 \text{ MPa} \end{aligned}$$

Corrected shear strength

$$\begin{aligned} Fv' &= 0.8 \times 4.5 \\ &= 3.6 \text{ MPa} \end{aligned}$$

Corrected tensile strength parallel to the grain

$$\begin{aligned} Ft' &= 0.8 \times 19 \\ &= 15.2 \text{ MPa} \end{aligned}$$

Corrected fiber-parallel compressive strength

$$\begin{aligned} Fc' &= 0.8 \times 25 \\ &= 20 \text{ MPa} \end{aligned}$$

Corrected uniform flexural modulus of elasticity

$$\begin{aligned} E05' &= 10,779.840 \text{ MPa} \\ &= 10,779.840 \text{ N/mm}^2 \end{aligned}$$

Formwork width reviewed

$$b_{bek} = 1 \text{ m} = 1000 \text{ mm}$$

Formwork thickness

$$H_{bek} = 0.012 \text{ m} = 12 \text{ mm}$$

Formwork specific gravity

$$G_{bek} = 0.5$$

Formwork weight

$$\begin{aligned} Q_{bek} &= L_{bek} \times H_{bek} \times G_{bek} \\ &= 0.006 \text{ kg/m} \end{aligned}$$

Cross-sectional area of formwork beam

$$\begin{aligned} A &= b_{bek} \times h_{bek} \\ &= 1000 \times 700 \\ &= 700,000 \text{ mm}^2 \\ Q_{bal} &= b_{bek} \times \text{Concrete Volume Weight} \\ &= 1680 \text{ kg/m} \end{aligned}$$

Then, from the above data, the reaction and moment are calculated based on the structural model in Figure 5. With a time factor (λ) = 0.8.

$$\begin{aligned} Rv_{bek} &= \tfrac{1}{2} \times (Q_{bal} + Q_{bek}) \times L \\ &= \tfrac{1}{2} \times (1680 + 0.006) \times 0.115 \\ Rv_{bek} &= 96.600 \text{ kg} \end{aligned} \quad (2)$$

$$\begin{aligned} M_{bek} &= \tfrac{1}{8} \times (Q_{bal} + Q_{bek}) \times L^2 \\ &= \tfrac{1}{8} \times (1680 + 0.006) \times 0.115^2 \\ M_{bek} &= 2.777 \text{ kg·m} \\ Vu &= \tfrac{Rv_{bek} \times 1.2}{\lambda} \\ &= \tfrac{96,600 \times 1.2}{0.8} \\ &= 144.9 \text{ kg} \\ Vu &= 1449 \text{ N} \end{aligned} \quad (3)$$

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$$\begin{aligned} \text{Mu} &= \frac{\text{M}_{\text{bek}} \times 1.2}{\lambda} \\ &= \frac{2.777 \times 1.2}{0.8} \\ &= 4.1655 \text{ kg·m} \\ \text{Mu} &= 41,655 \text{ N·mm} \end{aligned} \tag{4}$$

From the plywood data above, we can see the flexural, shear, and deflection controls that occur on plywood boards:

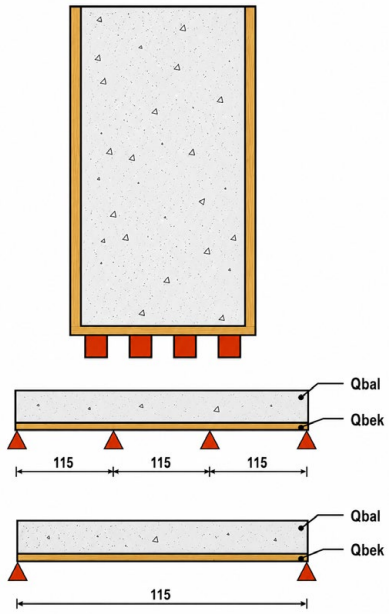


Figure 5. Floor Structural model (Source: researcher).

Flexural control:

$$\begin{aligned} \text{Cm} &= 0.85 \\ \text{Ct} &= 1 \\ \text{Cf} &= 1.4 \\ \text{F}'_{\text{b-ter}} &= \text{Cm} \times \text{Ct} \times \text{Cf} \times \text{F}'\text{b} \\ &= 0.85 \times 1 \times 1.4 \times 16 \\ \text{F}'_{\text{b-ter}} &= 19.04 \text{ N/mm}^2 \end{aligned} \tag{5}$$

$$\begin{aligned} \text{W} &= \frac{\text{b} \times \text{h}^2}{6} \\ &= \frac{1000 \times 12^2}{6} \\ \text{W} &= 24,000 \text{ mm}^3 \end{aligned} \tag{6}$$

$$\begin{aligned} \text{Mu} &< 0.85 \times \text{F}'_{\text{b-ter}} \times \text{W} \\ 41.655 \text{ N·mm} &< 0.85 \times 19.04 \times 24,000 \\ 41.655 \text{ N·mm} &< 388,416 \text{ N·mm} \end{aligned} \tag{7}$$

Slider control:

$$\begin{aligned} \text{Cm} &= 0.85 \\ \text{Ct} &= 1 \\ \text{Ch} &= 1.67 \end{aligned}$$

$$\begin{aligned} \text{F}'_{\text{v-ter}} &= \text{Cm} \times \text{Ct} \times \text{Ch} \times \text{F}'\text{v} \\ &= 0.85 \times 1 \times 1.67 \times 3.6 \\ \text{F}'_{\text{v-ter}} &= 5.110 \text{ N/mm}^2 \end{aligned} \tag{8}$$

$$\begin{aligned} \mathrm{Vu} &< 0.75 \times \frac{2}{3} \times \mathrm{b_{bek}} \times h_{\mathrm{bek}} \times \mathrm{F'_{v\text{-}ter}} \\ 1.449\ \mathrm{N} &< 0.75 \times \frac{2}{3} \times 1000 \times 12 \times 5.110 \\ 1.449\ \mathrm{N} &< 30,660\ \mathrm{N} \end{aligned} \tag{9}$$

Deflection control:

$$\begin{aligned} I &= \tfrac{b \times h^3}{12} \\ &= \tfrac{1000 \times 12^3}{12} \\ &= 144,000\ \mathrm{mm}^4 \end{aligned} \tag{10}$$

$$\begin{aligned} \delta &= \tfrac{5 \times (Q_{bal} + Q_{bek}) \times L^4}{384 \times E05 \times I} \\ &= \tfrac{5 \times (1680 + 0.000006) \times 115^4}{384 \times 10,779.840 \times 144,000} \\ \delta &= 0.0025\ \mathrm{mm} \\ \delta &< \tfrac{L}{300} \\ 0.0025\ \mathrm{mm} &< \tfrac{115}{300} \\ 0.0025\ \mathrm{mm} &< 0.383\ \mathrm{mm} \end{aligned} \tag{11}$$

where the deflection according to SNI 7973-2013 is $\ell/300$ [19].

Because δ is smaller than $\ell/300$, the plywood is safe, so the contractor provides additional beams under the plywood to increase strength.

3.2. Analysis of Retaining Beams and Support Beams

In formwork construction, retaining beams and support beams are used as shown in Figure 4. The retaining beams and support beams are made of meranti wood. The data on meranti wood is as follows [20].

Specific gravity

$$G = 0.8$$

Corrected uniform bending modulus of elasticity

$$E05' = 14,065.28\ \mathrm{MPa}$$

Bending strength

$$Fb = 12.6\ \mathrm{MPa}$$

Shear strength

$$Fv = 1.48\ \mathrm{MPa}$$

Tensile strength parallel to grain

$$Ft = 11.1\ \mathrm{MPa}$$

Compressive strength parallel to the grain

$$Fc = 11.1\ \mathrm{MPa}$$

Corrected flexural strength

$$\begin{aligned} Fb' &= 0.8 \times 12.6 \\ &= 10.08\ \mathrm{MPa} \end{aligned}$$

Corrected shear strength

$$\begin{aligned} Fv' &= 0.8 \times 1.48 \\ &= 1.18\ \mathrm{MPa} \end{aligned}$$

Corrected tensile strength parallel to the grain

$$\begin{aligned} Ft' &= 0.8 \times 11.1 \\ &= 8.88 \text{ MPa} \end{aligned}$$

Corrected fiber parallel compressive strength

$$\begin{aligned} Fc' &= 0.8 \times 11.1 \\ &= 8.88 \text{ MPa} \end{aligned}$$

From the data above, an analysis of the retaining beam can be performed, in accordance with its profile data in the form of flexural, shear, and deflection control.

The reactions and moments that occur in the retaining beam are shown in Figure 6 below.

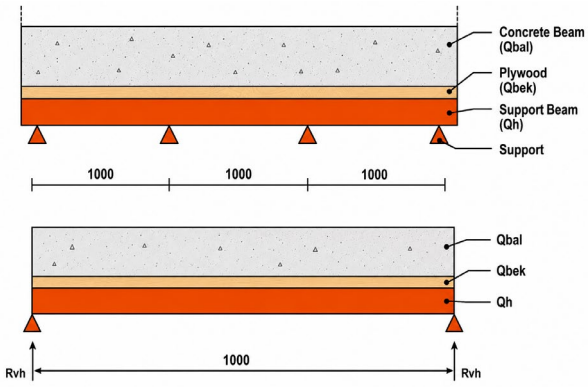


Figure 6. Retaining beams structural model (Source: researcher).

Weight of retaining beam.

$$\text{Height (h)} = 70 \text{ mm} = 0.07 \text{ m}$$

$$\text{Width (b)} = 50 \text{ mm} = 0.05 \text{ m}$$

Weight of retaining beam

$$\begin{aligned} Q_{Retaining} &= (b \times h \times G) \\ &= (0.05 \times 0.07 \times 0.8) \\ &= 0.003 \text{ kg} \end{aligned} \quad (12)$$

Dead load weight

$$\begin{aligned} Q_{Dead\ load} &= Q_{bal} + Q_{bek} + Q_{Retaining} \\ &= 588 + 0.006 + 0.003 \\ &= 588.009 \text{ kg/m} \end{aligned} \quad (13)$$

Total load

$$\begin{aligned} q_h &= \frac{Q_{\text{Dead load}} + 20\%}{4\ Segmen} \\ &= \frac{588.009 + 20\%}{4} \\ &= 176.402 \text{ kg/m} \end{aligned} \quad (14)$$

$$\begin{aligned} Rv_h &= \tfrac{1}{2} \times q_h \times \ell \\ &= \tfrac{1}{2} \times 176.402 \times 1 \\ &= 88.201 \text{ kg} \end{aligned} \quad (15)$$

$$\begin{aligned} M_h &= \tfrac{1}{8} \times q_h \times \ell^2 \\ &= \tfrac{1}{8} \times 176.402 \times 1^2 \\ &= 22.050 \text{ kg·m} \\ Vu &= \tfrac{\text{Rv}_\text{h} \times 1.2}{\lambda} \\ &= \tfrac{88.201 \times 1.2}{0.8} \\ &= 132.302 \text{ kg} \\ &= 1323.02 \text{ N} \\ Mu &= \tfrac{\text{M} \times 1.2}{\lambda} \\ &= \tfrac{22.050 \times 1.2}{0.8} \\ &= 33.075 \text{ kg·m} \\ &= 330,750 \text{ N·m} \end{aligned} \tag{16}$$

After obtaining the ultimate load, the strength and safety of the formwork support beams can be checked.

Flexural check:

$$\begin{aligned} F'_{b\text{-}ter} &= 0.85 \times 1.0 \times 1.40 \times 10.08 \\ &= 12.00 \text{ N/mm}^2 \end{aligned} \tag{17}$$

$$\begin{aligned} W &= \tfrac{\left(\text{b} \times h^2\right)}{6} \\ &= \tfrac{\left(50 \times 70^2\right)}{6} \\ &= 40,833.3 \text{ mm}^3 \end{aligned} \tag{18}$$

Flexural control: if the ultimate moment load (Mu) is smaller than the moment capacity of the beam cross-section, then the construction is safe with the following calculation.

$$\begin{aligned} Mu &< (0.85 \times W \times F'_{b\text{-}ter}) \\ 330.750 \text{ N·mm} &< (0.85 \times 40,833.3 \times 12.00) \\ 330.750 \text{ N·mm} &< 416,499.66 \text{ N·mm} \end{aligned} \tag{19}$$

Shear control:

$$\begin{aligned} \text{F}'_{\text{v-ter}} &= 0.85 \times 1.0 \times 1.67 \times 1.17 \\ &= 1.661 \text{ N/mm}^2 \end{aligned} \tag{20}$$

Shear control: if the ultimate shear load (Vu) is less than the shear cross-section capacity of the beam, then the beam construction is safe with the following calculation

$$\begin{aligned} Vu &< 0.75 \times \left(\frac{2}{3} \times h \times b\right) \times F'_{v\text{-}ter} \\ 1323.02 \text{ N} &< 0.75 \times \left(\frac{2}{3} \times 70 \times 50\right) \times 1.661 \\ 1323.02 \text{ N} &< 2906.75 \text{ N} \end{aligned} \tag{21}$$

Deflection control:

Deflection control: if the deflection that occurs (δ) is smaller than the allowable deflection ($\ell/300$) for a two-span beam, then the beam construction is safe against deflection with the following calculation:

$$\delta = \frac{5 \times \text{q}_\text{h} \times \ell^4}{384 \times \text{E05} \times \text{I}} \tag{22}$$

With details

$$\begin{aligned} I &= \tfrac{\left(\text{b} \times h^3\right)}{12} \\ &= \tfrac{\left(50 \times 70^3\right)}{12} \\ &= 1,429,166.6 \text{ mm}^4 \end{aligned} \tag{23}$$

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So, with the existing values, the above equation yields the following values:

$$\begin{aligned} \delta &= \frac{5 \times 0.1764 \times 1000^4}{384 \times 14,065.28 \times 1,429,166.6} \\ \delta &= 0.114 \text{ mm} \\ 0.114 \text{ mm} &< 3.333 \text{ mm} \end{aligned} \tag{24}$$

Meanwhile, the deflection of the permit is ($\ell/300$) = 3.333 mm.

Since δ is smaller than $\ell/300$, the formwork beam is safe from deflection.

After that, the support beam was checked. In accordance with the profile data, flexural, shear, and deflection checks were carried out in the same way as for the retaining beam.

The loads acting on the support beams include the load of fresh concrete beams, the load of plywood boards, and the load of retaining beams.

Weight of support beam

Height (h) = 120 mm = 0.12 m

Width (b) = 60 mm = 0.06 m

Support beam weight

$$\begin{aligned} q_m &= b \times h \times G \\ &= 0.06 \times 0.12 \times 0.8 \\ q_m &= 0.00576 \text{ kg/m} \end{aligned} \tag{25}$$

Then, the reaction force (Rv) and maximum moment (M) occurring on the support beam are calculated based on the structural model in Figure 7.

$$\begin{aligned} Rv_{t1} &= \tfrac{1}{2} \times (\tfrac{1}{2}\, Rv_h + Rv_h + Rv_h + \tfrac{1}{2}\, Rv_h) \\ Rv_{t1} &= \tfrac{1}{2} \times (44.101 + 88.201 + 88.201 + 44.101) \\ &= 132.302 \text{ kg} \end{aligned}$$

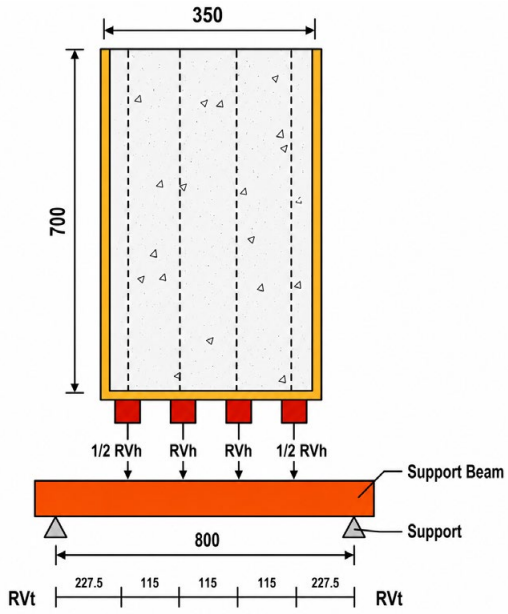


Figure 7. Support beams model (Source: researcher).

$$\begin{aligned} \text{Mc} &= \text{Rv}_{t1} \times 227.5 \\ &= 132.302 \times 227.5 \\ &= 30,098.705 \text{ kg·mm} \\ \text{Md} &= \text{Rv}_{t1} \times (227.5 + 115) - \tfrac{1}{2} \times \text{Rv}_{\text{h}} \times 115 \\ &= 132.302 \times (342.5) - \tfrac{1}{2} \times 88.201 \times 115 \\ &= 40,241.820 \text{ kg·mm} \\ \text{Me} &= \text{Rv}_{t1} \times (400) - \tfrac{\text{Rv}_{\text{h}}}{2}\left(115 + \tfrac{115}{2}\right) - \text{Rv}_{\text{h}}\tfrac{115}{2} \\ &= 40,241.820 \text{ kg·mm} \end{aligned} \tag{26}$$

After calculating the moments Mc, Md, and Me, the largest value is taken for further calculation.

$$Me = 40,241.820 \text{ kg·mm}$$

Next, after calculating Me, Mtotal is found using the following method.

$$\begin{aligned} \text{Rv}_{t2} &= \tfrac{1}{2} \times \text{q}_{\text{m}} \times \text{L} \\ &= \tfrac{1}{2} \times 0.00576 \times 1 \\ &= 0.003 \text{ kg} \end{aligned} \tag{27}$$

A difficult moment

$$\begin{aligned} Mm &= \tfrac{1}{8} \times q_m \times \ell^2 \\ &= \tfrac{1}{8} \times 0.00576 \times 1^2 \\ &= 0.00072 \text{ kg·mm} \\ &= 0.72 \text{ kg·mm} \end{aligned} \tag{28}$$

$$\begin{aligned} M_{total} &= Mm + Me \\ &= 0.72 + 40,241.820 \\ &= 40,242.54 \text{ kg·mm} \end{aligned} \tag{29}$$

$$\begin{aligned} Rv_{total} &= Rv_{t1} + Rv_{t2} \\ &= 132.302 + 0.003 \\ &= 132.305 \text{ kg} \end{aligned} \tag{30}$$

Use the load factor with the equation

$$\begin{aligned} Mu &= \tfrac{(M_{total} \times 1.2)}{\lambda} \\ &= \tfrac{40,242.54 \times 1.2}{0.8} \\ &= 60,363.81 \text{ kg·mm} \\ &= 603,638.1 \text{ N·mm} \\ Vu &= \tfrac{Rv_{total} \times 1.2}{\lambda} \\ &= \tfrac{132.305 \times 1.2}{0.8} \\ &= 198.458 \text{ kg} \\ &= 1984.58 \text{ N} \end{aligned} \tag{31}$$

Flexural control:

$$\begin{aligned} F'_{b\text{-}ter} &= 12.00 \text{ N/mm}^2 \\ W &= \tfrac{\left(60 \times 120^2\right)}{6} \\ &= 144,000 \text{ mm}^3 \end{aligned} \tag{32}$$

$$\begin{aligned} Mu &< 0.85 \times W \times F'_{b\text{-}ter} \\ 603,638.1 \text{ N·mm} &< 1,468,800 \text{ N·mm} \end{aligned} \tag{33}$$

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Shear control:

$$\begin{aligned} F'_{v\text{-}ter} &= 1.661\ N/mm^2 \\ Vu &< 0.75 \times \frac{2}{3} \times b \times h \times F'_{v\text{-}ter} \\ 1984.58\ N &< 0.75 \times \frac{2}{3} \times 60 \times 120 \times 1.661 \\ 1984.58\ N &< 5979.6\ N \end{aligned} \quad (34)$$

Deflection control:

$$\begin{aligned} I &= \frac{(b \times h^3)}{12} \\ &= \frac{(60 \times 120^3)}{12} \\ &= 8,640,000\ mm^4 \\ \delta &= \frac{5 \times q_m \times \ell^4}{384 \times E05 \times I} \\ &= \frac{5 \times 0.00000576 \times 1000^4}{384 \times 14,065.28 \times 8,640,000} \\ &= 6.075 \times 10^{-10} < 2.67\ mm \end{aligned} \quad (35)$$

(because the results of small deflections are ignored)

$$\begin{aligned} \delta &= \frac{\frac{1}{2}RV_h \times a_1\left(3l^2 - 4(a_1)^2\right) + RV_h \times a2 \times \left(3l^2 - 4(a_1)^2\right)}{24 \times E \times I} \\ &= \frac{44.101 \times 227.5\left(3(800)^2 - 4(227.5)^2\right) + 88.201 \times (227.5 + 115) \times \left(3(800^2) - 4(342.4)^2\right)}{24 \times 14,065.28 \times 8,640,000} \\ &= 0.021\ mm < 2.667\ mm \end{aligned} \quad (36)$$

Since δ is smaller than $\ell/300$, the formwork beams are safe against deflection.
Construction safety factor calculation is done as follows.
Flexural control on plywood boards:

$$\begin{aligned} EV &= 388.416\ N{\cdot}mm/41.655\ N{\cdot}mm \\ &= 9.32 \end{aligned}$$

Based on the criteria in Table 1, this board construction is safe and inefficient. For other controls and constructions, calculations can be made according to the example above. The results of the above construction calculations can be summarized in Table 2 below.

Table 2. Results of formwork structure control.

Construction	Control	Values and Conditions	EV	Description
Plywood	Flexural control	$Mu < 0.5 \times F'_{b\text{-}ter} \times W$ $41.655\ N{\cdot}mm < 388.416\ N{\cdot}mm$	9.32	Safe and inefficient
	Shear control	$Vu < 0.75 \times 2/3 \times b_{bek} \times h_{bek} \times F'_{v\text{-}ter}$ $1449\ N < 30,660\ N$	21.16	Safe and inefficient
	Deflection control	$\delta = 0.025\ mm$ $0.0025\ mm < 0.383\ mm$	153.2	Safe and inefficient
Retaining Beam	Flexural control	$Mu < (0.85 \times W \times F'_{b\text{-}ter})$ $330,750\ N{\cdot}mm < 416,499.66\ N{\cdot}mm$	1.26	Safe and very efficient
	Shear control	$Vu < 0.75 \times (2/3 \times h \times b) \times F'_{v\text{-}ter}$ $1323.02\ N < 2906.75\ N$	2.20	Safe and efficient
	Deflection control	$\delta = 0.893\ mm$ $0.114\ mm < 3.333\ mm$	29.24	Safe and inefficient
Support Beam	Flexural control	$Mu < 0.85 \times W \times F'_{b\text{-}ter}$ $603,638.1\ N{\cdot}mm < 1,468,800\ N{\cdot}mm$	2.43	Safe and efficient
	Shear control	$Vu < 0.75 \times 2/3 \times b \times h \times F'_{v\text{-}ter}$ $1984.58\ N < 5979.6\ N$	3.01	Safe and efficient
	Deflection control	$\delta < (\ell/300)$ $0.021\ mm < 2.667\ mm$	127	Safe and inefficient

Table 2 above shows that the plywood boards used in the flexural control, shear control, and deflection control yielded results of EV > 4. According to the criteria in Table 1, the use of plywood boards is safe but inefficient, resulting in material waste, especially in terms of the 5/7 casing wood, of which four pieces were installed. This condition can be optimized by reducing the number of rafters to 3 pieces. Another alternative is to use 10 mm thick plywood. Furthermore, on the flexural and shear control beams, EV = 1.26 and 2.20 were obtained, which are in accordance with safe and efficient criteria. Meanwhile, on the deflection control, EV = 29.24 was obtained, which is considered inefficient. Then, for the support beams controlling bending and shear, EV = 2.43 and 3.01 are obtained, which meet the safety and efficiency criteria. Meanwhile, for the deflection control, EV = 127 is obtained, which is inefficient.

4. Conclusions

From the analysis results, it was found that the load flow was from the weight of the concrete to the plywood board, to the support beams, to the bearing beams, and then to the scaffolding and finally to the foundation.

In general, the construction of the plywood boards, flexural control, shear, and deflection are safe but inefficient due to the plywood being too thick and the distance between the support beams being too close. The support beams and bearing beams are safe in terms of flexural control, shear, and deflection, but inefficient in terms of deflection control.

The efficient use of formwork timber is obtained from the planned flexural strength and shear strength. Furthermore, for implementation, the plan is made in the form of shop drawings.

The formwork construction can be used properly, but in reality, contractors remove the formwork structure too quickly, even though the concrete is not yet ready to bear the load, causing cracks in the lower part of the concrete beams. Cracks in the beams occur due to tensile forces on the lower part of the beams, as shown in Figure 8.



Figure 8. Cracks in beams (Source: researcher).

During project implementation, technical data related to the implementation of wooden formwork must be available and supported by strength analysis.

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