Analysis of Use Formwork and Slipform Pavers in Making Concrete Barrier on Toll Road Project

Akhmad Taufik Aditama[1,*], Nina Saraswati[2], Puthut Omar Satriawan[3]
[1] Road and Bridge Construction Engineering Technology Study Program, Department of Civil Engineering, Banyuwangi State Polytechnic
[2] Civil Engineering Study Program, Department of Civil Engineering, Yos Soedarso University of Surabaya
[3] Road and Bridge Construction Engineering Technology Study Program, Department of Civil Engineering, Banyuwangi State Polytechnic

Email: [1,*] akhmadtaufik@poliwangi.ac.id, [2] ninauniyos@gmail.com, [3] puthutomar@poliwangi.ac.id,

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Abstract

This study aims to compare the performance of concrete barrier making use manual formwork and slipform paver methods in terms of productivity, implementation duration, and work costs on the Kayu Agung–Palembang–Betung (KAPB) Toll Road Project Package II Section 1. Research data were obtained from field observations on several work cycles including cycle time, production volume, number of workers, tool usage, and implementation costs of each method. The research method used is quantitative descriptive analysis by comparing productivity, time, and costs based on actual field data. The results show that the average productivity of concrete barrier making use manual formwork is around 122 m per cycle, while the use of slipform paver reaches around 150 m per cycle, or around 23% higher. From the duration aspect, the slipform paver method is able to accelerate the completion of work by around 245 days or 46.01% compared to manual formwork. From the cost aspect, the use of slipform paver results in cost savings of Rp 3.82 billion or 14.3%. The discussion of the results shows that the superiority of the slipform paver is mainly due to the continuity of the molding process and the elimination of the formwork dismantling and installation formwork but is highly dependent on the continuity of the concrete supply and the readiness of the equipment path. Based on these results, it can be concluded that the slipform paver provides better performance than manual formwork in the context of the project studied, while still considering the limitations of field operational conditions.

Keywords: *Concrete Barrier, Manual Formwork, Slipform Paver, Productivity, Construction Costs*

1. Introduction

Trans Sumatra Toll Road (JTTS) is a national strategic project, the construction of which affects the Sumatra island and the national economic development [1]. The construction of the JTTS began in 2015 and is planned to be completed along 2,812 km. The construction is being carried out on the island of Sumatra with an investment value of Rp 538 trillion [2].

One of the JTTS projects currently under construction is Kayu Agung-Palembang-Betung (KAPB) toll road Package II Section 1, located in South Sumatra. The project, spanning 20.1 kilometers, is undergoing accelerated construction. Acceleration is being carried out across all aspects, including the construction of concrete barrier. Concrete barriers are road infrastructure components made of concrete that function to limit, direct, and maintain traffic safety [3].

Size of the JTTS project and the project completion demands progressiveness, so it is only natural that work process must be carried out using innovative, effective and efficient resources. Based on the work schedule, concrete barrier construction plan until 87th week is 4,691 m. However, realization in the field until 87th week only produced 682 m. One of the things that is considered to cause delay in process of making the road barrier using manual formwork, because there are processes of installation, making, concrete hardening processes, dismantling and mobilization of formwork.

Existing condition of making concrete barrier still uses manual formwork. Formwork is a series of wooden planks, plywood, metal plates, and similar materials assembled together to form a concrete mold. The choice of formwork for a building project affects the cost, time frame, and quality of construction [4]. The use of manual formwork for concrete barrier making is considered easier and cheaper. The use of manual formwork for concrete barrier making in the KAPB Toll Road Project Package II Section 1 is considered less effective and efficient. This is because the concrete barrier making process is carried out repeatedly, in prototype form, and the work volume is large. Manual formwork requires a lot of labor and materials [5]. Besides requiring relatively large amounts of labor and materials, manual formwork also produces waste material from the fabrication and dismantling processes, which results in additional time and costs for site cleanup. Several studies have shown that a suboptimal formwork system can reduce concrete work productivity and increase project indirect costs [6][7]. This becomes even more crucial on toll road projects, where delays in one work item can impact the rest of the project.

Concrete barrier making work is something that is highly considered in the KAPB Package II Section 1 toll road project. This is because concrete making work requires large costs, in addition to the duration of the work implementation greatly affects the concreting work [8]. In fact, according to [9] the costs for formwork and assembly range from 40% - 60% of the cost of concrete work or around 10% of the total construction costs for building work. Other studies state that the efficiency of the repeated concrete printing method is a major factor in controlling the costs and time of large-scale infrastructure projects [10].

As technology advances in the construction sector, concrete making continues to experience innovation. One of these innovations is the use of heavy equipment, namely the Slipform Paver. Heavy equipment is a crucial factor in projects, especially construction, mining, and other large-scale operations [11]. Making concrete barriers using a slipform paver can increase productivity by 30–50% and reduce dependence on manual labor, especially in rigid pavement work [12][13].

However, most research on slipform pavers focuses on concrete pavement applications and the technical aspects of the equipment, while studies specifically addressing concrete barrier molding are limited. Furthermore, studies directly comparing manual formwork and slipform pavers based on actual productivity data, cycle time, and direct costs within a single, integrated evaluation framework are rare, particularly in the context of toll road projects in Indonesia. This situation indicates a research gap that needs to be bridged.

Based on the above description, a comparative study is needed to compare the production capacity, time, and cost of using manual formwork versus slipform pavers for concrete barrier construction. This will help us understand the differences between the two tools. This study is expected to provide scientific contributions and practical recommendations for selecting methods to accelerate concrete barrier construction on toll road projects.

2. Methodology Of Research

The concrete barrier was cast using two molding methods: manual formwork and slipform paver. The analysis focused on three main parameters: productivity, implementation time, and direct costs, with data obtained through direct field observations at the KAPB Toll Road Project Package II Section 1 in South Sumatra Province. The research phase was carried out sequentially, starting from field data collection, productivity and time data processing, to cost analysis.

Concrete barrier made using manual formwork and slipform pavers have similar shapes, dimensions, and layouts. However, the type of ready-mix concrete used in each tool is different. Manual formwork uses ready-mix concrete FC 20 slump $\pm$ 10 cm, while slipform pavers use ready-mix concrete FC 20 slump 4-5 cm. The use of both tools as concrete barrier molds was then analyzed based on production capacity, processing time, and cost. Overall, the research stages carried out are described in more detail as follows:

Concrete Barrier Construction

In the KAPB Toll Road Project Package II Section 1, there are two tools for making concrete barriers:

A. Formwork

Formwork is a temporary mold used to support the load while the concrete is poured, shaped, and hardened. Because it acts as a temporary mold, the formwork is removed when the poured concrete has reached sufficient strength [15]. There are several aspects that must be considered when using formwork in concrete construction projects. These aspects are [16]:

a. Quality of the formwork must be precise, suitable, and conform to the planned structural shape. The surface of the formwork used must be flat to produce a good concrete surface.
b. Construction safety, the formwork must be strong enough to hold the concrete so that it does not collapse.
c. The cost of using formwork must be planned economically.

The concrete barrier was constructed with manual formwork using ready-mix concrete FC 20 slump $\pm$ 10 cm. The ready-mix concrete was transported from the batching plant using a truck mixer to job site, then poured using a casting bucket and a mobile crane. The detailed stages of concrete barrier molding are as follows:

1. Survey and marking location
2. Preparation of work permits and completeness of resources
3. Lean concrete work/ work floor
4. Install the assembled reinforced concrete
5. Install drained formwork and PVC pipe
6. Install concrete barrier formwork
7. Checklist before making of concrete barrier
8. Take concrete sample from a truck mixer
9. Making concrete barrier
10. Concrete hardening process
11. Dismantle the formwork
12. Finishing of the concrete barrier
13. Cleaning and mobilization of formwork

Figure 1. Concrete Barrier Making with Manual Formwork

B. Slipform Paver

Slipform paver is a machine for making rigid concrete, with a slipform frame as its main structure. This tool is used for accurate concrete placement, creating a smooth and even surface, compacting the concrete efficiently, and producing high-quality results [17].

Concrete barrier was constructed with slipform barrier using ready-mix concrete FC 20 slump 4-5 cm. Ready-mix concrete was transported from the batching plant using a truck mixer to job site, then poured into a heavy equipment conveyor. The concrete was then transported to the molding machine and compacted. This process was carried out while the heavy equipment was running without waiting for the hardening process.

Slipform paver uses Gomaco GT-3600 product, 74-horsepower (55 kw) engine, 48-volt generator, 24-inch (610 mm) radius, and three tracks. The moulding height (t) > 1 m, making speed (v) upto 11 m/min, and the work efficiency factor (Fa) 0,83. Details of the concrete barrier making stages are as follows:

1. Survey and marking location
2. Preparation of work permits and completeness of resources

3. Lean concrete work/ work floor
4. Install the assembled reinforced concrete
5. Install drained formwork and PVC pipe
6. Setting slipform paver
7. Checklist before making of concrete barrier
8. Take concrete sample from a truck mixer
9. Making concrete barrier
10. Finishing of the concrete barrier

Figure 2. Making Concrete Barrier with Slipform Paver

Concrete Barrier

Concrete barrier are road dividers designed for permanent construction, used for arterial roads or toll roads which function as a tool to direct traffic flow and road divider [14].

Figure 3. Concrete Barrier on Toll Road

Sampling and Observation

Data collection was conducted using a time study and work sampling method on concrete barrier printing activities. The analysis was determined as one work cycle for each printing method. The manual formwork method was observed over 3 work cycles, each representing a printing length of ± 40 m. The slipform paver method was observed over 3 printing cycles, each with a production length of ± 150 m. Observations were conducted under normal weather conditions.

Work Time Analysis and Production Capacity

Productivity and implementation time were measured by recording the start and finish times of each activity using a project work time and digital stopwatch. Primary activities included equipment/formwork installation, casting, and finishing, as well as supporting activities, including site preparation, reinforcement installation, and equipment mobilization. Productivity was calculated in meters per hour and meters per day, then averaged across the entire observation cycle. All measurements were conducted by the same researcher to minimize conflicting observations. Work duration was calculated based on productivity in hours or days. Production capacity in hours or days is influenced by the resources used. Work duration was obtained from field observations.

Analysis is based on the issue of cost and time of the work. More details are shown as follows [18]:

1) Production capacity / hour, based on making length (Q1):

Q1 = v x Fa x 60
Equipment coefficient / m2:
E 02 = 1 / Q1

2) Production capacity / hour based on making volume (Q2):
Q2 = v x b x Fa x 60 x t
Equipment coefficient / m3:
E 02 = 1 / Q2
Description:
Q : Production Capacity
V : Equipment Speed
B : Handling Width
FA: Equipment Efficiency Factor
T : Thickness

Cost Analysis

Calculation of job costs in the budget plan uses direct costs. Direct costs can be calculated by examining the shop drawing, analyzing the Burgerlijke Openbare Werken (BOW), SNI, Bina Marga, and field experience. Costs are calculated based on average productivity results obtained from field observations, so that work duration and costs are directly related to empirical data. The equation for calculating costs is shown in more detail below [19].
Job cost = Volume x Unit Price of Work
The unit price of the work consists of the cost of materials, wages and equipment costs.

3. Results and Discussion

This section discusses the making of concrete barrier using manual formwork and slipform pavers. The review cover direct cost, time, and productivity for each barrier making tool. To obtain complete data, field observation were reviewed and recorded. Once the data was obtained, calculation and analysis were performed. As a starting point, the following data is obtained from the S-curve analysis. Concrete barrier work data was taken from the KAPB Toll Road Project Package II Section 1:

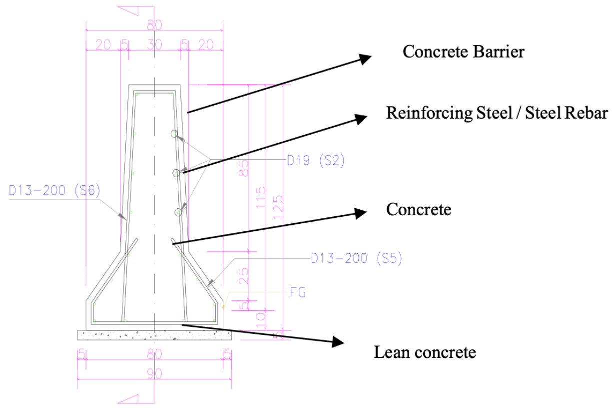

Figure 4. Size dan Dimension of Concrete Barrier

According to the plan, the concrete barrier making has a total volume of 2,1540 m and will be completed within 532 days, so that daily productivity must reach a minimum of 40.5 m. Until the 87th week, the concrete barrier making was planned to be 4,691 m, but the realization in the field only produced 682 m. So far, the concrete barrier making has been carried out using manual formwork.

Based on the schedule, concrete barrier work is progressing late. Delays can be caused by various factors, including: production of formwork, installation and dismantling formwork, a limited labor, waiting for concrete to harden, and impact of other projects. Therefore, efforts must be made to complete the work within specified timeframe, one of which is the use of a slipform paver to produce the concrete barrier.

Identification of Work, Materials and Equipment

Identification of work, material, and equipment is intended to determine the exact amount needed for use. The following are the results of identification of needs for each equipment:

Table 1. Identification of Work, Material and Equipment with Formwork

No	Description	Unit
A	**Work**	
1	Making concrete with Formwork	m^2
2	Formwork Installation and Dismantling	m^3
3	Rebar Installation and Fabrication	kg
B	**Material**	
1	Concrete fc' 30 (Slump 10)	m^3
2	Reinforcing Steel	kg
3	Pipe PVC 3/4"	unit
4	Pipe PVC 4"	unit
C	**Equipment**	
1	Crane	hour
2	Concrete Vibrator	hour
3	U-Head	pcs
4	Main Frame	pcs
5	Ladder Frame	pcs

Source: Observation Results

Table 2. Identification of Work, Material and Equipment with *Slipform Paver*

No	Description	Unit
A	**Work**	
1	Making concrete with Heavy Equipment	m^3
2	Rebar Installation and Fabrication	kg
3	Finishing	m^2
4	Cutting Concrete	m
B	**Material**	
1	Concrete fc' 30 (Slump 4)	m^3
2	Reinforcing Steel	kg
3	Pipe PVC 4"	unit
C	**Equipment**	
1	Slipform Paver	hour

Source: Observation Results

Productivity and Duration of Work

Productivity and work duration analysis was conducted through direct field observations. The underlying consideration for field observations is that the data obtained more accurately reflects actual conditions. The analysis of productivity and work duration using each making method in one day is shown below:

A. Calculation of time when using Formwork

In field observations, the cycle time for concrete barrier work using manual formwork was obtained with the following details.

Table 3. Cycle Time for Making Concrete Barriers Using Manual Formwork

No	Activity	Day					
		0.5	1	1.5	2	2.5	3
1	Marking						
2	Rebar Installation						
3	Install Formwork						
4	Install Scaffolding						

5	Making Concrete
6	Concrete Hardening
7	Formwork Dismantling
8	Finishing

Job Non Formwork
Job Bekisting
Source: Observation Results

Table 3 shows that for concrete barrier molding work using manual formwork, one cycle takes 3 days. In one cycle, the concrete barrier molding work can be completed along a length of 40 meters with a workforce of 6 people and using 16 sets of manual formwork. Based on this data, the production capacity is obtained: $\frac{40\ \text{m}}{6\ \text{person}} = 6{,}67\ \text{meter/cycle/person}$. Based on the results of these calculations, it will take time to complete all the work using manual formwork: $\frac{21.540\ \text{m}}{40\ \text{m}}\ \text{X}\ 3\ \text{day} = 1.616\ \text{day}$

According to the planned schedule, the remaining work time is 532 days. Therefore, to complete the concrete barrier within that timeframe, 40.7 m of concrete must be produced per day, or 122 m in one cycle. So, to producing concrete barrier 122 m/day requires workforce: $\frac{122\ \text{m}}{40\ \text{m}}\ \text{X}\ 6\ \text{person} = 19\ \text{person}$

B. Calculation of time when using slipform paver

Based on heavy equipment manuals, brochures, and interviews, cycle time for concrete barrier making was determined. Several types of work are included in one cycle, detailed as follows.

Table 4. Cycle Time of Making Concrete Barrier Using Slipform Paver

No	Activity	Day			
		0.5	1	1.5	2
1	Marking				
2	Rebar Installation				
3	Install Signs & Set Up Equipment				
4	Concrete Hardening				
5	Finishing				

Job Non Formwork
Job Bekisting
Source: Observation Results

Table 4 shows that the concrete barrier making process using slipform paver can take two days in one cycle. The machine's speed for making the concrete barrier is set at 0.5 meters per minute. This yields the following production capacity:

KP = V x Fa x 60 minutes
KP = 0,5 x 0.83 x 60
KP = 25 meter/hour
Description:
V = Speed
Fa = Equipment Efficiency (0,83)

Based on the data above, in one day (6 hours), making barriers with a slipform paver can produce a length of 25 meters x 6 hours = 150 meters. Therefore, it takes time to complete the entire job: $\frac{21.540\ \text{m}}{150\ \text{m/day}}\ \text{X}\ 2 = 287\ \text{day}$

From the productivity and work duration calculations, a summary of duration for use two concrete barrier making equipment until the project is completed obtained as follows.

Table 5. Duration of Work

No	Equipment	Duration (day)
1	Manual Formwork	532
2	Slipform Paver	287

Source : Calculation Results

Table 5 shows that making concrete barriers using heavy equipment can save up to 245 days or around 46.1% of time compared to using manual formwork.

Cost Analysis

Cost calculations reviewed include materials, tools, and labor. From the identification in Table 1 and 2, material and tool requirements for each equipment use are directly multiplied by the purchase price and the rental price. Calculations of work, materials, tool, and labor until project completion can be seen in Table 6 and 7, as well as a summary in Table 8 below.

Table 6. Cost Analysis Using Manual Formwork

No	Description	Volume	Unit	Unit Price		Total Price	
A	**Work**						
1	Formwork Installation + Dismantling	300.00	m²	Rp	70,000	Rp	21,000,000
2	Making Concrete	68.10	m³	Rp	45,000	Rp	3,064,543
3	Rebar Installation and Fabrication	6523.20	kg	Rp	800	Rp	5,218,560
B	**Material**						
1	Concrete fc' 30 (Slump 10)	68.10	m³	Rp	939,600	Rp	63,987,662
2	Reinforcing Steel	6523.20	kg	Rp	7,000	Rp	45,662,400
3	Pipe PVC 3/4"	30.00	unit	Rp	35,000	Rp	1,050,000
4	Pipe PVC 4"	20.00	unit	Rp	210,000	Rp	4,200,000
C	**Equipment**						
1	Crane	8.0	hour	Rp	347,500	Rp	2,780,000
2	Concrete Vibrator	8.0	hour	Rp	36,206	Rp	289,648
3	U-Head	768.00	pcs	Rp	800	Rp	614,400
4	Main Frame	192.00	pcs	Rp	850	Rp	163,200
5	Ladder Frame	192.00	pcs	Rp	850	Rp	163,200
	Amount					**Rp**	**148,193,613**

Source : Calculation Results

Table 6 shows price for each cycle of concrete barrier making work with a production length of 40 m is Rp. 148,193,613. However, this price does not include the procurement of manual formwork. To complete the entire work including the procurement of manual formwork, the costs required are: $\frac{21.540 \text{ m}}{122 \text{ m/day}}$ x Rp. 148.193.613 + (3 formwork group x Rp. 5.597.476) = Rp. 26.617.546.002

Table 7. Cost Analysis Using Manual Slipform Paver

No	Description	Volume	Unit	Unit Price		Total Price	
A	**Item Works**						
1	Making Concrete	85.13	m³	Rp	45,000	Rp	3,830,679
2	Rebar Installation and Fabrication	8154.00	kg	Rp	800	Rp	6,523,200
3	Finishing	420.00	m²	Rp	5,250	Rp	2,205,000
4	Cutting Concrete	75.00	m	Rp	20,000	Rp	1,500,000
B	**Material**						
1	Concrete fc' 30 (Slump 4)	85.13	m³	Rp	939,600	Rp	79,984,578
2	Reinforcing Steel	8154.00	kg	Rp	7,000	Rp	57,078,000
3	Pipe PVC 4"	25.00	pcs	Rp	210,000	Rp	5,250,000
C	**Equipment**						
1	Slipform Paver	6.00	hour	Rp	400,000	Rp	2,400,000
	Total					**Rp**	**158,771,457**

Source : Calculation Results

Table 7 shows price for each cycle of concrete barrier making work with a production length of 150 m is Rp. 158,771,456. However, this price does not include the concrete cover. To complete the entire job, including the concrete cover, required are: $\frac{21.540 \text{ m}}{150 \text{ m/day}}$ x Rp. 158.771.456 = Rp. 22.584.181.156 + Rp. 2.650.000 = Rp. 22.808.231.156

Table 8. Cost of Work

No	Equipment	Price (Rp)
1	Manual Formwork	Rp 26.617.546.022
2	Slipform Paver	Rp 22.808.231.156
	Deviation	**Rp. 3.815.314.846**

Source : Calculation Results

Table 8 shows that making concrete barriers using heavy equipment can save costs of Rp. 3.815.314.846 or approximately 14,3% compared to using manual formwork.

4. Conclusions and Suggestions

Conclusions

1. Making a concrete barrier using a slipform paver yields a speed of 150 m/cycle, exceeding the 122 m/cycle required using manual formwork. This is because using a slipform paver eliminates the need for dismantling and installing formwork, scaffolding, and waiting for the concrete to harden, resulting in a shorter cycle time.
2. Using a slipform paver can complete the project in 287 days, compared to 532 days for the same volume of work using manual formwork. Therefore, the slipform paver can accelerate the project by 245 days, or approximately 46.01%, primarily due to the elimination of formwork dismantling and waiting for the concrete to harden.
3. Casting the concrete barrier using a slipform paver is estimated to cost Rp 22,802,231,156, more economical than using manual formwork, which costs Rp 26,617,546,003. Using a slipform paver can save Rp 3.82 billion, or 14.3%, compared to manual formwork methods. These cost savings apply under certain operational conditions, such as continuous concrete supply, ready equipment routes, and efficient working hours.

Suggestions

The use of slipform pavers must be accompanied by reliable concrete supply planning, equipment path readiness, and the availability of experienced operators to achieve optimal performance. Further research requires analysis with a greater number of observation cycles and a longer observation period, so that the effects of weather factors, concrete supply disruptions, differences in crew skills, and maintenance costs and downtime of slipform paver machines can be analyzed more quantitatively.

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