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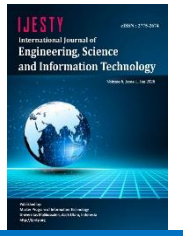

Engineering Analysis of Implementation and Cost of Parapet Precast with Parapet Conventional/In-situ

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Abstract

A parapet is a solid side barrier installed on the edge of elevated structures such as bridges, pile slabs, or BUP at toll roads/ freeways. One innovation that can be developed to overcome the problems of conventional (in-situ) methods is the use of precast parapets, which can be produced in workshops or fabrication sites. Therefore, it is necessary to analyze the structural design, implementation method, and cost aspects that will be presented in this research. This study uses precast parapet designs with 2 different dimensions, namely 2.5 m long in straight alignment and 1.5 m long in superelevation alignment, used in bridge structures or pile slabs in toll road construction. Engineering analysis of precast parapets is carried out to determine the performance of precast parapets against impact loads. Precast concrete is produced in a workshop location and then transported to the project site, and it has advantages over conventional methods. Based on engineering analysis, a precast parapet design calculation analysis has been carried out, which is expected to withstand an impact load of 21.5 tons. Assuming 100 m in terms of time, the manufacture of precast parapet is one day faster than the conventional/in situ method. In addition, less labor is required, where precast parapets require 23 people, while conventional parapets require 28 people. In terms of cost, with a length of one meter, the precast parapet is 26.41% more expensive than the conventional/in situ method. Therefore, future studies should combine life-cycle cost analysis and life-cycle assessment with full-scale lateral or impact testing in order to create a more thorough technical, economic, and environmental foundation for deciding between precast and cast-in-situ parapet systems.

Keywords: *Engineering Analysis, Parapet, Precast, Life-Cycle Cost.*

1. Introduction

A parapet is a solid side barrier placed on the edge of elevated structures such as bridges, pile slabs, or BUP at toll roads and freeways. Its purpose is to serve as a safety guard to prevent vehicles from falling off elevated structures that are designed to withstand vehicle impacts according to safety standards. There are two methods for constructing concrete parapets: the conventional (in-situ) method and the precast method. When using the conventional (in-situ) approach, potential issues can arise, such as uneven surfaces and connections, and the leakage of cement water due to improperly sealed formwork.

One innovation that can be developed to address the issues of conventional (in-situ) methods is the use of precast parapets, which can be manufactured in workshops or fabrication sites. Precast parapets are expected to reduce implementation time, improve labor efficiency, and ensure consistent quality, thereby minimizing the risk of nonconformity. However, using precast parapets presents several challenges, such as the connection between elements, stability during installation, impact resistance, and cost considerations. Therefore, analyzing structural design, installation methods, and cost factors is essential and will be discussed in this research. Additionally, this study aims to contribute to developing standards for the use of precast parapets in construction. The cost analysis (RAB) involves calculating the expenses for materials, wages, and other costs related to producing precast parapets.

This study is of strategic importance because it supports project acceleration, labor efficiency, consistent quality, the utilization of production facilities within the company's ecosystem, and the development of standardized construction methods that can be replicated across various projects, as well as establishing a technical and managerial foundation for HKI to determine when industrialization through precast construction yields higher project value compared to conventional methods.

2. Literature Review

A literature review was conducted on precast fabrication techniques, their impact on time and labor productivity, and the costs involved in applying fabrication methods in the field. An in-depth analysis was performed, identifying potential obstacles that could hinder the fabrication process and exploring ways to improve construction productivity. Additionally, it was found that while the fabrication method can accelerate construction time, it is less cost-effective compared to conventional methods.

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2.1. Engineering Analysis

Engineering analysis of precast parapets is carried out to determine the performance of precast parapets against impact loads. Based on SNI 1725: 2016, a performance of 5 is determined, where the largest vehicle that will pass through is a van-type trailer truck with a weight of 220000 N and a speed of 80 km/h [1]. Further numerical investigations were carried out for the hybrid parapet to offer design suggestions concerning construction factors and additional improvements [2].

2.2. Parapet Product

Concrete is a mixture of Portland cement or other hydraulic cement, fine aggregate, coarse aggregate, and water, with or without additional admixtures [3],[4]. Concrete materials have been widely used for construction materials such as houses, buildings, dams, roads, and so on [5]. Currently, there are two systems for implementing concrete, namely the conventional system and the precast system.

Precast concrete is a concrete element or component without or with reinforcement that is molded before being assembled into a building [6]. The types of structural system components that are currently commonly used include floor plates, beams and girders, columns, walls, stairs, piles, and box culverts [7],[8],[9]. Precast concrete is produced in a workshop location and then transported to the project site [10]. And has advantages over conventional methods, such as [11]:

a. Precast concrete fabrication can be done without the effects of weather; it can be done in a closed workshop.
b. Efficient in terms of human labor by utilizing technology.
c. good quality and maintained with strict control so that product uniformity is obtained.
d. Precast mass production can be done without waiting for land readiness.
e. The duration of work becomes shorter, and the implementation method produces formwork material optimally.

According to some experts, there are several categories of barriers to the use and implementation of precast concrete methods, such as not being flexible to changes, engineering problems, monotonous aesthetics, limited space availability, being more expensive, no demand for precast concrete, and insufficient information [12], [13]

A parapet is a support on the left or right side for vehicle safety and as a bridge barrier to make road users more comfortable. Precast is concrete that has been prepared for casting, pouring, and curing at a location that is not the destination where this method is used to avoid expensive transportation costs (or VAT in some countries). Generally, a high-value-added product where manufacturing and transportation costs are cheaper [14]. A precast parapet is quickly installed on the bridge deck with mechanical anchors and does not present shrinkage-induced cracking as its deformations are free to occur before its installation [15]. 14 activities have been identified in this research, namely reparation, position survey, adjustment material installation, precast parapet panel shifting from trailer to the top of the deck slab, precast parapet panel distribution, precast parapet panel installation, rebar parapet installation for concrete stitch, sealing work, concrete casting, formwork dismantling, and finishing [16].

2.3. Cost Analysis (RAB)

The cost analysis (RAB) is a calculation of the amount of costs required for materials and wages, and other costs related to the production of precast parapets, so that it can be used as a reference in the implementation of the project [17]. Project RAB is an estimate of the costs required for each job in a construction project, so that the total cost required to complete a project can be obtained.[18]. The Project Budget Plan (RAB) is a calculation of the amount of costs required for materials and wages, as well as other costs associated with the implementation of the building or project [19], [20]. In the girder beam structure, the cost comparison between the precast concrete method and the conventional concrete method for the bridge girder beam can be concluded that the precast concrete method is 15.63% more expensive than the conventional concrete method [17].

2.4. Software MIDAS

The finite element method is a numerical procedure for analyzing structures and continuity. In general, the problem at hand is too complicated to be solved using traditional analytical approaches [21]. The finite element method is used to model structures using small, connected elements called finite elements. Each finite element has a displacement function. Each element, including nodes, boundaries, and surfaces, is interconnected and connected, either directly or indirectly, with every other element through a common interface [22]. The behavior of a particular node in terms of the properties of every other element in the structure can be determined using the stress/strain properties of the materials used to build the structure [23]. The entire set of equations defines the properties of each node, resulting in a sequence of equations in algebra written in matrix notation [24].

MIDAS is a Finite Element Method (FEM) program. The software generates forces (BM, SF, etc.) on each part and combines them according to predefined combinations [25]. The required input data includes material characteristics, including time effects, structural geometry, external loads, superimposed dead loads, and the definition of moving loads, if any [26] The output data obtained from the simulation results include normal stress, force, shear stress, displacement, reaction, and the envelope of all these results [27]

For the development of previous research, this study uses precast parapet designs with 2 different dimensions, namely 2.5 m long in straight alignment and 1.5 m long in superelevation alignment, used in bridge structures or pile slabs in toll road construction. Engineering analysis using the MIDAS software to compute the performance of the precast parapet under impact load.

3. Methods

The manufacture of precast parapets was carried out at the Jambi 2 Precast Plant of PT Semen Indogreen Sentosa (HK-SIS) located on Jalan Ness, Simpang Sungai Duren, Jambi Luar Kota District, Muaro Jambi Regency, Jambi Province, as shown in Figure 1. The flowchart of the research is as follows in Figure 2. The research method used in this study uses an analytical method with a quantitative approach through primary and secondary data collection.

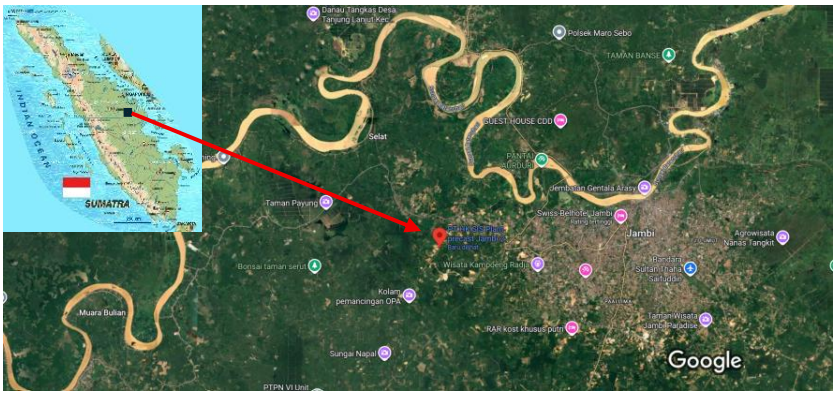

Fig 1. Production Location of Precast Parapet (Map Google, 2025)

3.1. Research Flowchart

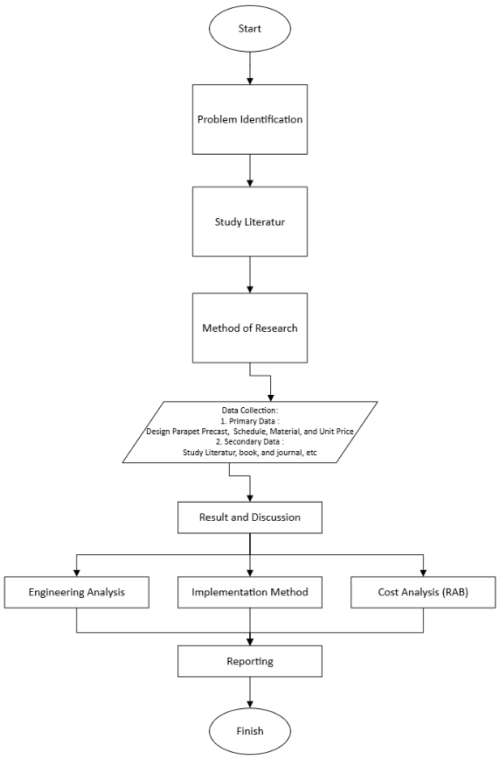

Fig 2. Flowchart of Research

3.2. Primary Data Collection

Primary data is data obtained from direct research results in the field as follows:
1. Design precast parapet used in bridge structures or pile slabs in toll road construction.
2. Schedule and materials to find out the time and materials needed for the project to run smoothly.
3. Unit price estimates the cost required for each job in the project analyzed.

3.3. Secondary Data Collection

Secondary data is data obtained indirectly or comes from books, literature, library sources, journals, and reliable institutions.

3.4. Data Analysis

Data analysis is carried out in the form of analyzing the cost budget plan and time analysis on the implementation of the project. Based on the data collected, the processing carried out in general can be described as follows:
a. Engineering Analysis of precast parapet
b. Creating time and labor requirements for conventional and precast methods.
c. Recapitulation analysis of the cost calculation results for conventional and precast methods.

4. Result and Discussion

The results of this study include the design of precast parapets in accordance with technical analysis, implementation methods in terms of time productivity, and cost analysis (RAB).

4.1. Engineering Analysis

The engineering analysis used MIDAS software to obtain the ability of the parapet design to meet the impact load, and in accordance with the technical criteria. The parapet design uses two types: type 1 with a length of 2.5 m for normal areas and type 2 with a length of 1.5 m for superelevation areas. The results of the analysis are as follows:

4.1.1 Impact Load Modeling

Impact load modeling used the Midas software in Figure 4, using the reference from SNI 1725:2016, with the equation obtained:

$$W = 220{,}000\ N \quad (1)$$

$$M = \frac{W}{g} = 24.729\ ton \quad (2)$$

$$v = 80\frac{km}{jam} = 22.222\frac{m}{s} \quad (3)$$

$$t = 0.6\ s \quad (4)$$

$$F = M.\frac{V}{t} = 830.90\ kN \quad (5)$$

$$\Phi = 15° \quad (6)$$

$$F_{long} = \cos\Phi.F = 802.6\ kN \quad (7)$$

$$F_{trans} = \sin\Phi.F = 215\ kN \quad (8)$$

Definition:

W : impact load (N)
M : impact mass (ton)
g : gravity force (kN/m^2)
v : velocity (m/s)
t : time (s)
Φ : impact angle (°)

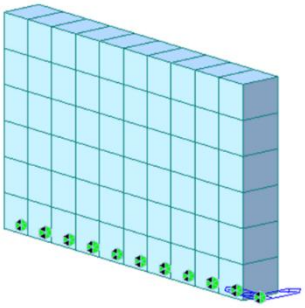

Fig 3. Output Model Analysis

The load used for the construction of precast parapets on bridge structures or pile slab on toll road construction is equivalent to a van-type trailer truck with a vehicle characteristic load (W) of 220,000 N and an impact angle of 15 °. The impact speed on the inner-city toll road, based on the regulation of the Minister of Transportation, PM 111 of 2015, is a maximum of 80 km/h. Based on the results in equation 8 of the loading analysis that has been carried out, it is found that the precast parapet can withstand a horizontal load (F_{trans}) Of 215 kN or 21.5 tons.

4.1.2 Reinforcement Analysis

Based on the analysis of the loading received by the precast parapet, a reinforcement design analysis is then carried out with MIDAS software with reference to the standard requirements van-type trailer truck vehicle in SNI 2847:2019 for structural concrete. In this model, the parapet structure is represented as a number of small elements connected to one another through nodal points. Each element has material properties, geometry, stiffness, and displacement and force relationships that are used to describe the structure's overall response to applied loads.

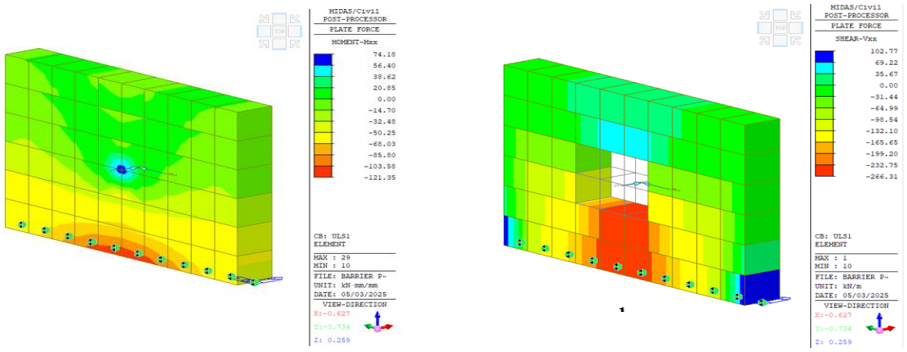

Fig 4. Output the force in moment (a) dan the force in shear (b)

Obtained value:

$M_u = 122\ kNm$ (9)

$M_n = T_{steel}(d_{tul} - \frac{d_c}{2})$=142 kNm (10)

$M_d = 0.9\ M_n = 127{,}72\ kNm$ (11)

Check, $M_d > M_u, OK$ (12)

Definition:

M_u : Ultimate moment (kNm)
M_n : Nominal moment (kNm)
T_{steel} : Steel quality (kN/m^2)
d_{tul} : Reinforce diameter (m)
d_c : concrete blanket (m)

The modeling results show that significant reactions occur in the area below the parapet, particularly around the junction between the parapet and the supporting structure. This is consistent with the behavior of the parapet as a cantilevered element, where horizontal loads at the top generate the largest moments at the base. The output from MIDAS shows in Figure 5. The distribution of moments and shear forces on the parapet surface, which is then used as a reference for determining the requirements for main reinforcement and shear reinforcement.

The resulting ultimate moment (M_u) is 122 kNm so that the nominal moment (M_n) of 142 kNm is obtained. The required design moment (M_d) Is 127,72 kNm. Trial and error was carried out to obtain the optimal reinforcement dimensions consisting of main reinforcement and shear reinforcement to withstand the moments that occur in precast parapets. So based on the results of the analysis, the design of the main reinforcement in the upper reinforcement uses D13-150, the lower reinforcement D16-150, and the shear reinforcement D13-200 and connection between the slab and precast parapet using D22-150 . Design of precast parapet in Figure 5 below:

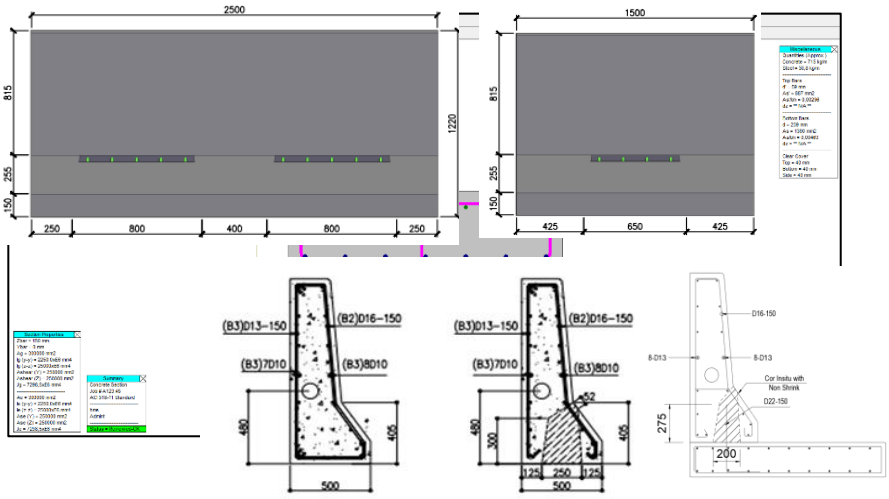

Fig 5. Desain and Connection Parapet Precast L=2,5 m dan L=1,5 m, Pot A-A dan Pot B-B

4.2. Implementation Product

Based on the results of the analysis and design drawings of the precast parapet, the trial work of making precast parapets is then carried out. Trial activities are expected to provide output related to the method of implementation, productivity in terms of time, and quality of the products. The trial method of making precast parapets using vertical steel molding and concrete quality FC 30 MPa is shown in Figure 7 below:

Fig 6. Casting of precast parapets using vertical molds

The productivity of precast parapet implementation in terms of time and resources is shown in Tables 1 and 2 below:

Table 1. Productivity Conventional Method

Konvensional Method (100 m)						
No	Description	Unit	Vol	Prod/Day	Duration (day)	Resource (person)
1	Reinforcement	kg	3338.92	4375	1	7
2	Formwork installation	m2	194.30	38.59	6	15
3	Concrete work	m3	35.40	12.5	3	6

Table 2. Productivity Precast Method

Precast Method (100 m)						
No	Description	Unit	Vol	Prod/Day	Duration (day)	Resource (person)
1	Fabrication Precast	m	100	16	6	9
2	Installation Precast	m	100	32	3	14

The table above shows that the production of 100 m of precast parapet can speed up the construction time by one day compared to the conventional/in situ method. Precast parapet production can be done at the beginning of the project without having to wait for land readiness. In addition, the resources required for precast parapet production are more efficient at 23 people compared to the conventional/in situ method of 28 people. The results of precast parapet products visually have a uniform color, flat texture, good edges/corners with minor finishing, and precise dimensions, as in Figure 8. In addition, the compressive strength test conducted at the age of 7 days (min 80%) and 28 days (>100%) has been fulfilled as shown in Table 3.

Fig 7. Product Parapet Precast

Table 3. Compressive Strength Test

No	Description	Compressive Strength Test		Passes/Not
		7 Days (Min 80% = 24 MPa)	28 Days (> 100% = 30 MPa)	
1	S-7-1	26.37	32.93	Passes
2	S-7-2	25.92	32.71	Passes
3	S-7-3	26.71	33.16	Passes

4.3. Cost Analysis (RAB)

Comparison of the cost of precast parapet work with conventional/in situ parapet is shown in Table 4 below.

Table 4. Cost Analysis Parapet Conventional vs Parapet Precast

No	Description	Unit	Parapet Conventional/m			Parapet Precast/m		
			Vol	Unit Price (Rp)	Price (Rp.)	Vol	Unit Price (Rp)	Price (Rp.)
A	Labor							
1	Worker	hour	5,7729	18.720,02	108.068,80	2,6250	18.720,02	49.140,05
2	Labour	hour	0,7000	21.060,02	14.742,01	0,8750	21.060,02	18.427,52
3	Foreman	hour	0,5685	24.570,02	13.968,06	0,5685	24.570,02	13.968,06
B	Material							
1	Parapet Precast	m	-	-	-	1,0000	1.980.000,00	1.980.000,00
2	Concrete Class B1	m^3	0,4120	1.830.000,00	753.960,00	-	-	-
3	Bekisting (Barier)	m^2	1,2721	350.000,00	445.217,50	-	-	-
4	Curing Compound	kg	0,1717	62.100,00	10.663,91	-	-	-
5	Reinforcement	kg	42,391	13.741,00	582.497,48	-	-	-
6	Concrete non-shrink	m^3	-	-	-	0,0526	11.550.000,00	607.992,00
C	Equipment							
1	Truck Crane	hour	-	-	-	0,0091	1.038.300,00	9.448,53

2	Mobile Crane 30 Ton	hour	-	-	-	0,0091	1.502.000,00	13.668,20
3	Concrete Vibrator	hour	0,4016	30.400,00	12.208,64	-	-	-
4	Concrete Pump	hour	0,0612	1.638.700,00	100.288,44	-	-	-
5	Flat Bed Truck	hour	0,0542	1.353.400,00	73.354,28	-	-	-
6	Water Tank Truck	hour	0,0044	490.400,00	2.157,76	-	-	-
7	Air Compresor	hour	0,0612	211.300,00	12.931,56	-	-	-
	Sum Price/m (Rp.)				2.130.058,44			2.692.644,36
	Deviation (Rp)						562.585,91	
	Persen (%)						26.41	

Based on the table above, Although the initial cost of the precast parapet was determined to be 26.41% more than that of the conventional cast-in-situ method, this comparison only considers the direct construction cost and does not take into account the overall economic performance of the element over its entire service life. A comprehensive life-cycle cost analysis should consider expenses related to fabrication, transportation, installation, inspection, maintenance, repair, traffic management, lane closure, user delay, replacement, and the costs associated with the end of the product's life. The higher initial cost of using precast construction can be partially offset by a shorter time needed for on-site building, less need for labor, more consistent quality, a lower chance of early problems, and the option to replace damaged parts in a modular way after a vehicle collision. This point is especially important for toll road projects, as traffic interruptions and safety concerns in work zones can lead to significant indirect expenses.

5. Conclusion

Based on the research that has been done, the following conclusions can be obtained:

a. Engineering analysis, a precast parapet design calculation analysis has been carried out, which is expected to withstand an impact load of 21.5 tons. The design of the main reinforcement in the upper reinforcement uses D13-150, the lower reinforcement D16-150, and the shear reinforcement D13-200.
b. In terms of implementation method, assuming 100 m in terms of time, the manufacture of precast parapet is one day faster than the conventional/in situ method. In addition, less labor is required, where precast parapets require 23 people, while conventional parapets require 28 people.
c. In terms of cost, with a length of one meter, the precast parapet is 26.41% more expensive than the conventional/in situ method.

The strategic importance of precast parapets is reflected in their ability to cut down on the time needed for on-site construction, while also promoting industrialized building methods, standardized designs, regulated manufacturing processes, safer setup procedures, and the ability to replicate these structures across various toll-road projects. Therefore, future studies should combine life-cycle cost analysis and life-cycle assessment with full-scale lateral or impact testing in order to create a more thorough technical, economic, and environmental foundation for deciding between precast and cast-in-situ parapet systems.

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