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Comparative Analysis of Concrete Structure Bridges and Steel Structure Bridges in Terms of Economics

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ABSTRACT

This study compares the economic feasibility of concrete and steel bridges by analyzing material costs, maintenance expenses, and project efficiency. A comprehensive literature review highlights the advantages and limitations of each material. Concrete is recognized for its low initial cost, excellent compressive strength, and widespread availability, making it ideal for conventional bridge designs. Steel, on the other hand, offers superior tensile strength, high durability, and faster prefabrication, making it suitable for complex and long-span structures. The research methodology involves applying the Critical Path Method (CPM) for scheduling and cost analysis to determine the most efficient material choice based on project requirements. The findings reveal that while steel bridges have a higher initial cost, they may yield lower long-term maintenance expenses and greater structural adaptability. Conversely, concrete bridges are more favorable for short-term projects with immediate budget constraints. The results emphasize the importance of strategic material selection and efficient project scheduling to achieve optimal construction outcomes and cost management.

1. Introduction

A bridge is a structure that supports transportation facilities by connecting two sides of a road separated by obstacles such as rivers, valleys, or highways. Bridges play a crucial role in transportation by enabling people and vehicles to cross natural or artificial barriers quickly and efficiently. The presence of a bridge enhances mobility and economic development, reduces travel time, facilitates evacuation and emergency access, and infrastructure development. Bridges generally consist of several construction elements: solid foundations, support pillars, connecting structures like highways or railways, and roofs or safety rails on each side for safety. Bridges can be constructed from various materials such as steel or concrete, and they come in multiple designs and architectures, from ordinary to grand bridges. [1]

Environmental sustainability has become a primary focus in infrastructure development in this modern era. As demands for sustainable development rise, innovations in bridge design have become increasingly important to ensure infrastructure development meets transportation needs while positively impacting the environment. To reduce the ecological impact of construction projects, innovations in bridge design have become crucial to sustainability goals. The application of environmentally friendly materials, advanced technologies, and designs that support energy efficiency are the main aspects covered in innovations. [2]

For remote areas, bridges are essential for easing residents' access to their daily activities. However, difficult-to-navigate access roads complicate bridge construction, making transporting needed materials expensive compared to easily accessible areas. Consequently, building long-span or short-span bridges faces economic, access, and construction phase challenges. Comparing various grades of regular concrete with the desired bridge design is expected to yield efficient and safe design results, as bridge safety is a primary factor in bridge design to ensure the bridge withstands live and dead loads, thus providing user safety. [3]

Most bridge constructions in Indonesia, especially on county roads, use simple beam types (bridges on two supports). However, if not properly maintained, such bridges will suffer damage around the expansion joints and supports, impacting user comfort and leading to high maintenance costs. The solution is an integrated bridge design that combines the lower and upper structures into an integral bridge system. Integral bridges, made without movement between spans or between spans and abutments, can be constructed monolithically without expansion joints, reducing maintenance and joint and bearing replacement costs. [4]

Durability and cost planning focus on bridge structures. This study compares cost analyses for steel and concrete bridges.

2. Literature Review

2. 1 Theory and Basic Concepts of Steel and Concrete Bridges

Bridges are essential elements in transportation infrastructure, often using concrete and steel for their strength and durability. Concrete is known for its compressive strength, while steel excels in tensile strength and offers design flexibility [5]. Concrete is the most widely used construction material, with about three tons per person annually on Earth [6]. Material selection often depends on initial cost considerations, durability, and long-term maintenance needs.

2. 2 Economic Analysis of Steel Bridges

Steel bridges have cost-efficiency advantages, primarily due to prefabrication. Prefabrication allows bridge components to be produced off-site and transported to the construction site, reducing construction time and labor needs on-site [7]. This accelerates construction and reduces traffic disruption during construction. Although steel material costs may be higher initially, time and labor efficiency can lead to significant cost savings [8]. Additionally, steel bridges are more accessible to repair and update, extending their lifespan and reducing long-term maintenance costs.

2. 3 Economic Analysis of Concrete Bridges

Concrete is a popular material in bridge construction due to its high compressive strength and relatively low cost. Research shows that concrete bridges have advantages in terms of lower initial material costs and wide availability [9]. However, concrete also has disadvantages, such as the need for more frequent maintenance and potentially high repair costs [10], especially in harsh environmental conditions. Concrete is also prone to cracking and damage due to extreme temperature changes, which can affect the long-term durability of the bridge.

2. 4 Planning Calculations

During the early project stages, estimation information is often not very detailed, leading to less accurate results. Thus, a cost estimation model explaining most projects based on minimal information is needed. [11]. The CPM (Critical Path Method) is used to identify critical paths or work items. The CPM addresses issues with forward and backward calculations [12], speeding up bridge construction work and using S-curves to control projects by comparing design and field S-curves. [13]

3. Method

This research was conducted by searching journals from sources using predetermined keywords, then selecting journals based on "Bridge Planning," "Cost Efficiency in Bridge Construction," "Bridge Planning Management," and "Bridge Planning Management Analysis." This study uses CPM data analysis.

4. Result and Discussion

4.1 Critical Path Method (CPM)

The Critical Path Method (CPM) plans and controls project timelines. Network diagrams, often called arrow diagrams, depict activities with arrows using specific symbols. Forward and backward project duration calculations must be understood before creating a critical path in the Activity on Arrow (AOA) scheduling method. Terms related to forward and backward AOA calculations include:

- Early Start (ES): the earliest activity can start after the preceding activity finishes.
- Late Start (LS): the latest time an activity can finish without delaying the project schedule.
- Early Finish (EF): the earliest time an activity can finish if it starts at its earliest and is completed within its duration.
- Late Finish (LF): the latest time an activity can start without delaying project completion.

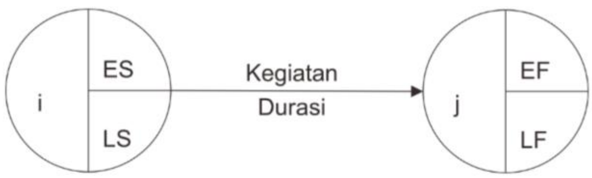


Figure 4.1 ES, LS, EF, LF

Two calculations are known in the AOA network to obtain the ES, LS, EF, and LF numbers, forward and backward. 1. Forward Calculation: In identifying the critical path, a method called forward calculation is used with the following rules:

- A new activity can only start if its predecessor activities have been completed except for the initial activity.

- The earliest start time for an activity is 0.
- The earliest finish time for an activity is equal to the earliest start time plus the duration of the activity.

4.2 Unit Price Analysis of Concrete Bridges

Reinforcement Work per 1kg

No	Uraian pekerjaan	Koefisien	satuan	harga satuan	Jumlah
				Rp.	Rp.
A	**Tenaga**				
	Pekerja	0.007	Oh	70,000.00	490.00
	Tukang besi	0.007	Oh	90,000.00	630.00
	Kepala tukang	0.0007	Oh	80,000.00	56.00
	Mandor	0.0004	Oh	100,000.00	40.00
			Jumlah tenaga kerja		1,216.00
B	**Bahan**				
	Besi beton ulir	1.15	Kg	13,200.00	15,180.00
	Kawat beton	0.015	Kg	18,000.00	270.00
			Jumlah bahan		15,450.00
C	**Peralatan**				
			Jumlah peralatan		0.00
D	Jumlah				16,666.00
E	Overhead & Profit 10% x D				1,666.60
F	Harga satuan pekerjaan				18,332.60

Concrete Pouring Work per 1 Meter

No	Uraian pekerjaan	Koefisien	satuan	harga satuan	Jumlah
				Rp.	Rp.
A	**Tenaga**				
	Pekerja	0.1	Oh	70,000.00	7,000.00
	mandor	0.001	Oh	100,000.00	100.00
			Jumlah tenaga kerja		7,100.00
B	**Bahan**				
	Beton ready mix B-2 f'c 30 Mpa	1.02	M³	1,264,683.42	1,289,977.09
			Jumlah bahan		1,289,977.09
C	**Peralatan**				
	Truck mixer	0.12	jam	627,563.28	75,307.59
	Alat bantu	1	Ls	50,000.00	50,000.00
			Jumlah peralatan		125,307.59
D	Jumlah				1,422,384.68
E	Overhead & Profit 10% x D				142,238.47
F	Harga satuan pekerjaan				1,564,623.15

From the example AHSP table for reinforcement and concrete pouring work above, it can be concluded that:

- The cost of reinforcement work for Bore Pile using deformed bars per kg is Rp. 13,200.
- Concrete pouring costs for ready-mix concrete B-2 fc' 30 MPa is Rp. 1,264,683.42, and the rental price for a Truck Mixer per hour is Rp. 627,563.28.

4.3 Cost Planning Calculation

4.2.1 Concrete Bridge Construction

- Materials

  The formula is Price x coefficient x volume. The price of Ready Mix concrete quality B-2 fc' 30 is Rp. 1,264,683.42. The coefficient for the material is 1.02. And the casting volume is 847.80 cubic meters. So, Rp. 1,264,683.42 x 1.02 x 847.80 = Rp. 1,093,642,575.55.

- Equipment
  The formula is the Number of equipment x rental time x rental price. According to the duration calculation, three truck mixers were used for 34 hours, less than four days. The rental price for one truck mixer is Rp. 627,563.28 per hour. So, 3 x 34 hours x Rp 627,563.28 = Rp 63,845,777.85.
- Labor
  The formula is the total Number of workers x worker's wages. In the duration calculation, 20 workers are needed for four days, with five workers per day.
- Bill of Quantities

No	Uraian Pekerjaan	Harga Total (Rp)	
A	Persiapan dan Survey	Rp	50,000,000.00
B	Pembersihan Lahan	Rp	38,146,781.43
C	Pengeboran	Rp	505,015,298.91
D	Pembesian	Rp	16,588,871,993.66
E	Pengecoran	Rp	16,760,398,179.18
F	Galian Struktur	Rp	67,888,388.67
	Jumlah	Rp	34,010,320,641.85
	PPN 10%	Rp	3,401,032,064.18
	Total	Rp	37,411,352,706.03
	Dibulatkan	Rp	37,411,352,750.00

4.2.2 Steel Bridge Construction

This RAB (Budget Plan) calculation results from the total worker costs, total equipment rental costs, and total material costs produced by the RAB, with estimated costs for each task as follows: Rp. 506,244,000 for preparation work, Rp. 468,549,462 for foundation work, Rp. 847,146,316 for structural work, Rp. 3,750,438,713 for drainage work, Rp. 14,742,000 for other costs, and the total RAB calculation obtained is Rp. 5,806,326,421.

No	URAIAN PEKERJAAN	VOLUME	SAT	JUMLAH BIAYA PEKERJA	JUMLAH BIAYA ALAT	JUMLAH BIAYA MATERIAL	TOTAL HARGA
a	b	c	d	e	f	g	
I	**PEKERJAAN PERSIAPAN**						
1	Mobilisasi dan demobilisasi	1.00		-	-	-	Rp 5,940,000
2	Pembersihan Lahan	927	m²	Rp 25,296,000.00	Rp 475,008,000	-	Rp 500,304,000
	JUMAH I						***Rp 506,244,000***
II	**GALIAN & TIMBUNAN**						
1	Galian Pondasi 0 - 2 m	333	m³	Rp 10,572,000.00	Rp 62,112,000	-	Rp 72,684,000
2	Galian Pondasi 2 - 4 m	333	m³	Rp 10,572,000.00	Rp 62,112,000	-	Rp 72,684,000
3	Galian Pondasi 4 - 6 m	333	m³	Rp 10,572,000.00	Rp 62,112,000	-	Rp 72,684,000
4	Timbunan Pondasi & Approach	1541	m³	Rp 10,572,000.00	Rp 62,112,000	Rp 177,813,462	Rp 250,497,462
	JUMLAH II						***Rp 468,549,462***
III	**PONDASI**						
	Sumuran						
	Abutmen 1	231	m³	Rp 43,215,000.00	Rp 43,332,800	Rp 337,025,358	Rp 423,573,158
	Abutmen 2	231	m³	Rp 43,215,000.00	Rp 43,332,800	Rp 337,025,358	Rp 423,573,158
	JUMLAH III						***Rp 847,146,316***
IV	**PEKERJAAN STRUKTUR**						
1	**Pile Cap**						
	Abutmen 1	83	m³	Rp 13,222,500.00	Rp 6,132,800	Rp 162,131,508	Rp 181,486,808
	Abutmen 2	83	m³	Rp 13,222,500.00	Rp 6,132,800	Rp 162,131,508	Rp 181,486,808
2	**Dinding Abutmen**						
	Abutmen 1	62	m³	Rp 19,815,000.00	Rp 7,812,800	Rp 234,771,127	Rp 262,398,927
	Abutmen 2	62	m³	Rp 19,815,000.00	Rp 7,812,800	Rp 234,771,127	Rp 262,398,927
3	**Head Wall Abutmen**						
	Abutmen 1	21	m³	Rp 27,907,500.00	Rp 7,812,800	Rp 86,140,378	Rp 121,860,678
	Abutmen 2	21	m³	Rp 27,907,500.00	Rp 7,812,800	Rp 86,140,378	Rp 121,860,678
4	**Wing Wall**						
	Abutmen 1	7	m³	Rp 13,222,500.00	Rp 6,132,800	Rp 76,774,124	Rp 96,129,424
	Abutmen 2	7	m³	Rp 13,222,500.00	Rp 6,132,800	Rp 76,774,124	Rp 96,129,424
5	**Plat Injak**						
	Abutmen 1	17	m³	Rp 13,222,500.00	Rp 6,132,800	Rp 106,264,831	Rp 125,620,131
	Abutmen 2	17	m³	Rp 13,222,500.00	Rp 6,132,800	Rp 106,264,831	Rp 125,620,131
6	**PCI Girder**	10	Buah	Rp 50,328,000.00	Rp 335,928,000	Rp 534,330,400	Rp 920,586,400
7	**Rc Plate**	459	Buah	Rp 36,504,000.00	Rp 53,280,000	Rp 149,175,000	Rp 238,959,000
8	**Slab**	232	m³	Rp 74,340,000.00	Rp 18,985,600	Rp 922,575,780	Rp 1,015,901,380
	JUMLAH IV						**Rp 3,750,438,713**
V	**DRAINASE**						
	Pipa 4"	96	m	Rp 5,655,000.00	-	Rp 1,152,000	*Rp 6,807,000*
	Deck Draine	24	buah	Rp 5,655,000.00	-	Rp 2,280,000	*Rp 7,935,000*
	JUMLAH V						**Rp 14,742,000**
VI	**FINISHING**						
	Bahu Jembatan						Rp -
	Kerb, Bahu jemnatan, dan Parapet	56	m³	Rp 13,185,000	Rp 8,905,600	Rp 93,529,600	Rp 115,620,200
	Asphal	64.5	ton	Rp 4,063,000	Rp 10,480,000	Rp 89,042,730	Rp 103,585,730
	JUMLAH VI						***Rp 219,205,930***
	TOTAL RAB						**Rp 5,806,326,421**

4.4 S-Curve

4.4.1 Concrete Bridge Construction

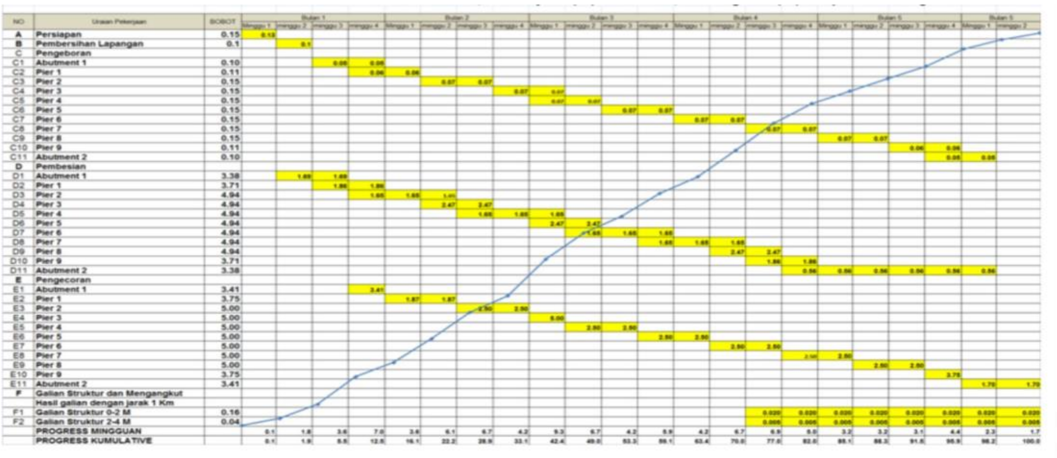
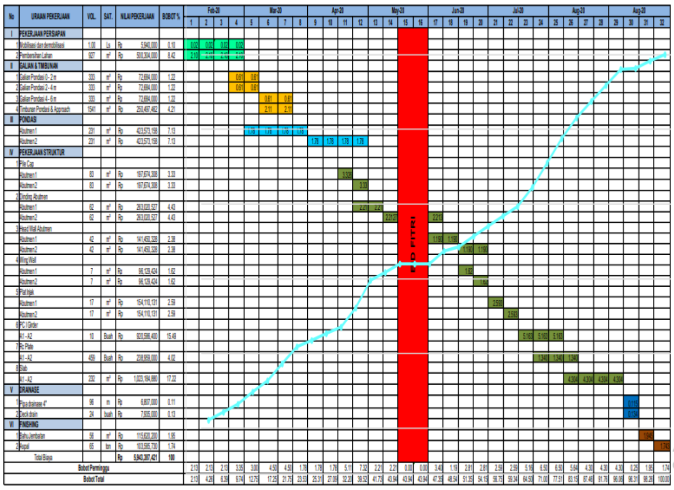


Figure 4.2 S-Curve for Concrete Bridge

4.4.2 Steel Bridge Construction

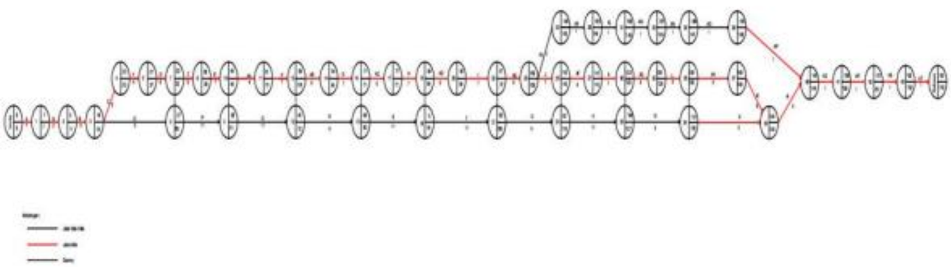


Gambar 4.3 Kurva S jembatan Baja

4.5 CPM Calculation Results

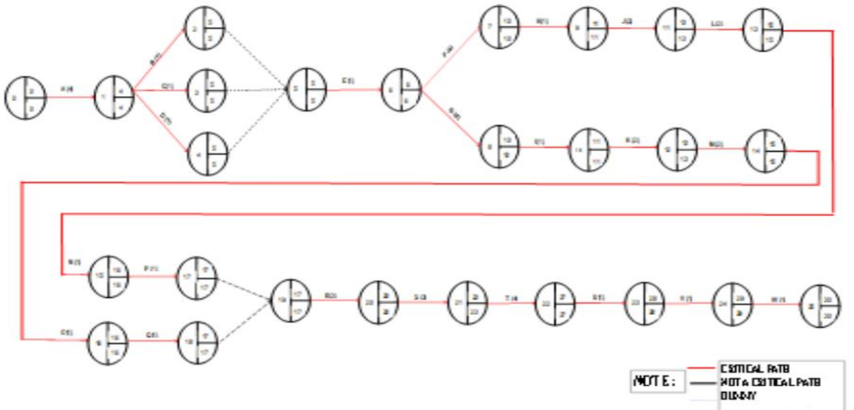
4.5.1 Concrete Bridge Construction

From the CPM results, it can be determined that the sequence of tasks is preparation work and clearing work, followed by rebar work from A1 to A2. After the rebar work at A1, it proceeds to drilling and casting from A1 to A2. Rebar and drilling can be done simultaneously, but rebar work must be completed before casting. During the casting work at point P6, structural excavation from A1 to A2 can also be done simultaneously. Thus, the critical path can be determined: preparation work – land preparation – drilling from A1 to A2 – rebar work at A1 and A2 – casting from A1 to A2 – structural excavation from P6 to A2.



4.5.2 Steel Bridge Construction

From the calculation of labor, equipment, and material costs, the resulting S-Curve is shown below, with the respective weights of each task. The S-Curve forms because, from week 1 to week 6, the project's progress is slow in the initial phase. This is followed by a rapid progression of activities from week 7 to week 28 over a more extended period. From week 29 to week 32, the rate of progress decreases, ending at the final point of the project with the curve tapering off.



4.6 CashFlow

4.6.1 Concrete Bridge Construction

Periode		Rencana Progres		Rencana Arus Kas		Bulanan
Bulan	Minggu	Minggu (%)	Komulatif (%)	Mingguan	Komulatif	
1	1	0.1	0.1	Rp 44,213,416.83	Rp 44,213,416.83	
	2	1.8	1.9	Rp 608,311,973.77	Rp 652,525,390.61	Rp 4,263,447,
	3	3.6	5.5	Rp 1,223,286,759.78	Rp 1,875,812,150.39	
	4	7.0	12.5	Rp 2,387,635,455.25	Rp 4,263,447,605.64	
2	1	3.6	16.1	Rp 1,217,080,589.57	Rp 5,480,528,195.21	
	2	6.1	22.2	Rp 2,063,576,734.44	Rp 7,544,104,929.65	Rp 6,991,729,
	3	6.7	28.9	Rp 2,275,782,932.56	Rp 9,819,887,862.21	
	4	4.2	33.1	Rp 1,435,289,458.53	Rp 11,255,177,320.75	
3	1	9.3	42.4	Rp 3,150,743,408.41	Rp 14,405,920,729.16	
	2	6.7	49.0	Rp 2,275,782,932.56	Rp 16,681,703,661.73	Rp 8,857,434,
	3	4.2	53.3	Rp 1,435,289,458.53	Rp 18,116,993,120.26	
	4	5.9	59.1	Rp 1,995,618,441.22	Rp 20,112,611,561.48	
4	1	4.2	63.4	Rp 1,435,289,458.53	Rp 21,547,901,020.02	
	2	6.7	70.0	Rp 2,275,782,932.56	Rp 23,823,683,952.58	
	3	6.9	77.0	Rp 2,355,129,184.64	Rp 26,178,813,137.22	
	4	5.0	82.0	Rp 1,706,069,594.99	Rp 27,884,882,732.21	Rp 7,772,271,
5	1	3.2	85.1	Rp 1,074,880,408.81	Rp 28,959,763,141.02	
	2	3.2	88.3	Rp 1,074,880,408.81	Rp 30,034,643,549.83	
	3	3.1	91.5	Rp 1,068,877,737.97	Rp 31,103,521,287.80	
	4	4.4	95.9	Rp 1,511,786,054.69	Rp 32,615,307,342.48	Rp 4,730,424,
6	1	2.3	98.2	Rp 797,160,030.13	Rp 33,412,467,372.61	
	2	1.7	100.0	Rp 587,930,225.28	Rp 34,010,320,641.85	Rp 1,385,090,
					TOTAL	**Rp 34,010,320,**

4.6.2 Steel Bridge Construction

PERIODE 2020 BULAN	NO	MATERIAL (RP)	ALAT (RP)	PEKERJA (RP)	TOTAL BIAYA PERMINGGU (RP)	TOTAL BIAYA PERBULAN (RP)	KUMULATIF (RP)	PRESENTASE %
FEBRUARI	1	-	Rp 118,752,000	Rp 6,324,000	Rp 125,076,000	Rp 661,234,731	Rp 125,076,000	Rp 2
	2	-	Rp 118,752,000	Rp 6,324,000	Rp 125,076,000		Rp 125,076,000	Rp 2.27
	3	-	Rp 118,752,000	Rp 6,324,000	Rp 125,076,000		Rp 125,076,000	Rp 2.27
	4	Rp 88,906,731	Rp 180,864,000	Rp 16,236,000	Rp 286,006,731		Rp 197,100,000	Rp 3.58
MARET	5	Rp 176,683,911	Rp 62,112,000	Rp 21,357,000	Rp 260,152,911	Rp 763,333,841	Rp 260,152,911	Rp 4.73
	6	Rp 87,777,180	Rp 62,112,000	Rp 21,357,000	Rp 171,246,180		Rp 171,246,180	Rp 3.11
	7	Rp 124,644,875	Rp 62,112,000	Rp 21,357,000	Rp 208,113,875		Rp 208,113,875	Rp 3.78
	8	Rp 95,200,875	Rp 17,760,000	Rp 10,860,000	Rp 123,820,875		Rp 123,820,875	Rp 2.25
APRIL	9	Rp 87,777,180	Rp 21,120,000	Rp 10,785,000	Rp 119,682,180	Rp 818,051,056	Rp 119,682,180	Rp 2.18
	10	Rp 87,777,180	Rp 22,212,800	Rp 10,785,000	Rp 120,774,980		Rp 120,774,980	Rp 2.20
	11	Rp 154,328,998	Rp 24,480,000	Rp 23,970,000	Rp 202,778,998		Rp 202,778,998	Rp 3.69
	12	Rp 337,336,498	Rp 13,358,400	Rp 24,120,000	Rp 374,814,898		Rp 374,814,898	Rp 6.82
MEI	13	Rp 67,580,972	Rp 3,360,000	Rp 13,260,000	Rp 84,200,972	Rp 168,326,944	Rp 84,200,972	Rp 1.53
	14	Rp 67,580,972	Rp 3,360,000	Rp 13,185,000	Rp 84,125,972		Rp 84,125,972	Rp 1.53
	15	EID FITRI						
	16							
JUNI	17	Rp 278,900,827	Rp 8,905,600	Rp 26,445,000	Rp 314,251,427	Rp 675,610,518	Rp 314,251,427	Rp 5.71
	18	Rp 7,834,323	Rp 3,360,000	Rp 13,185,000	Rp 24,379,323		Rp 24,379,323	Rp 0.44
	19	Rp 43,015,234	Rp 6,720,000	Rp 29,370,000	Rp 79,105,234		Rp 79,105,234	Rp 1.44
	20	Rp 213,543,334	Rp 17,811,200	Rp 26,520,000	Rp 257,874,534		Rp 257,874,534	Rp 4.69
JULI	21	Rp 63,384,767	Rp 3,360,000	Rp 13,185,000	Rp 79,929,767	Rp 712,837,874	Rp 79,929,767	Rp 1.45
	22	Rp 158,987,267	Rp 8,905,600	Rp 13,260,000	Rp 181,152,867		Rp 181,152,867	Rp 3.29
	23	Rp 157,299,120	Rp 11,976,000	Rp 16,776,000	Rp 186,051,120		Rp 186,051,120	Rp 3.38
	24	Rp 207,024,120	Rp 29,736,000	Rp 28,944,000	Rp 265,704,120		Rp 265,704,120	Rp 4.83
AGUSTUS	25	Rp 269,457,160	Rp 329,736,000	Rp 28,944,000	Rp 628,137,160	Rp 1,287,422,242	Rp 628,137,160	Rp 11.42
	26	Rp 221,015,694	Rp 21,120,000	Rp 30,678,000	Rp 272,813,694		Rp 272,813,694	Rp 4.96
	27	Rp 171,290,694	Rp 3,360,000	Rp 18,510,000	Rp 193,160,694		Rp 193,160,694	Rp 3.51
	28	Rp 171,290,694	Rp 3,360,000	Rp 18,660,000	Rp 193,310,694		Rp 193,310,694	Rp 3.51
SEPTEMBER	29	Rp 224,956,063	Rp 8,905,600	Rp 18,660,000	Rp 252,521,663	Rp 501,864,453	Rp 252,521,663	Rp 4.59
	30	Rp 3,432,000	-	Rp 11,310,000	Rp 14,742,000		Rp 14,742,000	Rp 0.27
	31	Rp 108,924,460	Rp 8,905,600	Rp 13,185,000	Rp 131,015,060		Rp 131,015,060	Rp 2.38
	32	Rp 89,042,730	Rp 10,480,000	Rp 4,063,000	Rp 103,585,730		Rp 103,585,730	
TOTAL		**Rp 3,764,993,858**	**Rp 1,305,748,800**	**Rp 517,939,000**	**Rp 5,588,681,658**	**Rp 5,588,681,658**	**Rp 5,499,774,927**	**Rp 100**

5. Conclusion

This document contains a cost comparison between the planning of a concrete bridge and a steel bridge to estimate costs in the construction industry. By making this comparison, it is found that planning a bridge using steel is more efficient than using concrete. Ultimately, CPM helps construction practitioners estimate costs and time in a tangible form. This is done by comparing the RAB, S-Curve, and CPM results as references. However, this comparison cannot be applied to all planning scenarios because it is intended to choose one option to optimize costs. This approach is only feasible when choosing between the two types of bridges is impossible.

References

[1] B. Setiawan and A. ,. A. Masagala, "Perancangan struktur Atas Jembatan Busur Baja Tipe Tied Arch Bridge Bentang 60 m," *Perencanaan jembatan,* pp. 1-1, 2020.

[2] F. f. gaol, "Inovasi Terkini Dalam Desain Jembatan Yang Ramah Lingkungan," *Inovasi desain jembatan,* pp. 2-2, 2023.

[3] E. C. M. Landeng, "Analisis Perencanaan Jembatan Selamat datang SP.II Timika," *jurnal teknik,* pp. 1-1, 2021.

[4] Y. Nurrizki and P. i. G. Raka, "Studi Perbandingan Efisiensi Struktur Atas Jembatan Beton Pratekan Antara Sistem Jembatan Konvensional dengan Jembatan Integral pada berbagai Variasi Bentang," *Analisis efisiensi perencanaan jembatan,* pp. 1-1, 2021.

[5] A. Z. Souza and J. Kim, "Performance Comparison of Steel and Concrete Bridges," *Journal of Bridge Engineering 28(3),* pp. 110-120, 2023.

[6] T. Hoang and P. Vu, "Global Usage of Concrete in Construction," *Construction Materials Journal 15(4),* pp. 455-468, 2020.

[7] L. K. S. Zhang and L. Nguyen, " Cost Efficiency in Steel Bridge Construction," *International Journal of Structural Engineering, 32(2),* pp. 98-105, 2021.

[8] L. Nguyen and L. Shen, "Economic Analysis of Prefabricated Bridge Elements," *Journal of Infrastructure Systems, 26(2),* 2020.

[9] M. Wang and H. Liu, "Durability and Maintenance of Concrete Bridges," *Journal of Civil Engineering and Management, 27(1),,* pp. 75-84, 2021.

[10] D. Garber and J. Shane, " Long-Term Cost of Concrete Bridge Maintenance," *Construction Management and Economics, 37(1),* pp. 1-14, 2019.

[11] Khamistan, "Analisis Estimasi Biaya dengan metode Cost Significant model sebagai dasar Perhitungan Konstruksi Jembatan Beton Bertulang," *Estimasi Perencanaan Jembatan,* p. 1, 2019.

[12] R. Ramadhani, I. Sumarman and A. Prasetyo, "Analisis Manajemen Konstruksi Jembatan Cinapel," *analisis manajemen konstruksi,* pp. 2-6, 2019.

[13] A. M. S, L. M. Hariani and Y. Frheza, "ANALISIS MANAJEMEN KONSTRUKSI JEMBATAN DI JALAN LINGKAR TIMUR," *analisis manajemen perencanaan jembatan,* pp. 5-6, 2022.

[14] B. d. Lestari and F. E. Nurhidayatullah, "Efektivitas Perencanaan Struktur Jembatan," *analisis efektivitas perencanaan jembatan,* pp. 1-1, 2019.

[15] E. G. Dwiyanto, "Analisis estimasi Biaya Dengan Metode Cost Significant Model Pads Konstruksi Jembatan Rangka Baja," *Estimasi biaya Perencanaan Jembatan,* p. 5, 2020.