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Comparative Analysis of Mechanical Coupler and Lap Splice Methods for Precast Beam Connection Based on Construction Duration

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ABSTRACT

Reinforcement splicing work in reinforced concrete structures has a significant impact on project efficiency, particularly in terms of construction duration and ease of execution on-site. However, research comparing the mechanical coupler and lap splice methods for splicing precast beams based on a detailed analysis of construction duration remains limited. This study aims to compare the effectiveness of beam joint construction durations using mechanical coupler and lap splice methods in the construction project of Mitra Plumbon Sumedang Hospital. The study employs a descriptive quantitative approach with a comparative method through field observations, interviews, and documentation. Data analysis was conducted using the PERT (Program Evaluation and Review Technique) method to obtain a more realistic estimate of work duration. The results of the study indicate that the lap splice method has a shorter average duration compared to the mechanical coupler method, both in the analysis of rebar joints and beam joints. The average duration for rebar joints using the lap splice method was 5 minutes and 18 seconds, while the mechanical coupler method took 5 minutes and 48 seconds. the lap splice method reduced the work duration by 8.62%, equivalent to approximately 30 seconds for each splice, In the analysis per beam joint, the lap splice method took 34 minutes and 22 seconds, while the mechanical coupler method took 39 minutes and 55 seconds, the time saving reached 13.90%, or approximately 5 minutes and 33 seconds. Nevertheless, the mechanical coupler method has advantages in terms of joint neatness and ease of installation in areas with high reinforcement density. Therefore, the selection of the connection method must be tailored to the characteristics and requirements of the construction project.

Keywords: *Mechanical Coupler; Lap splice; PERT; Construction Productivity; Precast Beam.*

1. Introduction

The development of construction technology encourages the use of increasingly effective and efficient implementation methods, especially in reinforced concrete structure work. In reinforced concrete construction, reinforcement joints are an important part because they function to maintain the continuity of forces between the reinforcement bars so that they can work as a single structure [1], [2]. The quality of the reinforcement joints greatly determines the performance of structural elements, because poor joints can reduce the capacity of the structure and have the potential to cause failure at the connection point [3], [4], [5]. In addition to the aspect of strength, the connection method also affects the efficiency of project implementation, especially in terms of work duration, labor needs, and ease of implementation in the field. In multi-storey building projects, delays in reinforcement joint work can affect the next stages of work, such as the installation of formwork, rebar placement, and casting, thus impacting the overall project schedule [6].

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In construction practice, reinforcement splicing is unavoidable due to the limitations of the standard length of reinforcing steel available on the market, while the requirements for reinforcement length on structures often exceed that size [7], [8]. The reinforcement joint functions to channel the force from one reinforcement rod to another so that the structural elements remain able to work intact and stably. Therefore, the selection of the connection method is an important aspect that needs to be considered not only in terms of structural strength, but also cost efficiency, labor productivity, and work execution time [9]. In modern construction projects, the selection of the right connection method is one of the strategies to increase the effectiveness of project implementation without compromising the quality of the resulting structure.

The most common method of reinforcement joint used in the field is lap splice. This method is carried out by stacking two rebar bars according to extend the length and then tied using bendrat wire. Lap splice is considered easy to implement because it does not require special tools and is commonly used in various construction projects. However, the use of overlap joints is considered less effective on main reinforcement because it requires a larger channel length so as to increase material use and reinforcement density in the joint area [10], [11]. High reinforcement density can complicate the casting process and potentially reduce the quality of structural work [12]. Along with the development of construction technology, a mechanical connection method using a mechanical coupler as an alternative to reinforcement connection has emerged. This system uses a threaded coupler to mechanically connect the two ends of the reinforcement so that it produces a more compact, neater connection, and is able to reduce the build-up of reinforcement in the joint area [13]. In addition, coupler joints are considered to have better quality control and are more practical in areas with high levels of reinforcement density [7].

The difference in characteristics between the lap splice method and the mechanical coupler method causes both methods to have their own advantages and disadvantages in the implementation of the project. The overlapping method tends to be simpler in terms of fabrication because it does not require additional processes such as making threads on the rebar, making it easier to apply in the field [6]. However, this method requires a larger connection length so that material consumption increases and the joint area becomes denser [10], [11]. High reinforcement density can complicate the casting process and affect the ease of carrying out structural work [12]. In contrast, the mechanical coupler method requires additional fabrication stages, such as cold forging and threading, so the production process becomes more complex and requires special tools [13]. However, the installation process in the field becomes more practical because the connection is carried out through a locking system between reinforcements, so that the connection is neater and the reinforcement density can be reduced [7], [8]. This condition shows that the effectiveness of a connection method is not only influenced by the installation process, but also by the entire stages of work from fabrication, material transfer, to installation in the field. Therefore, a thorough analysis of the duration of the work is important to find out the more efficient connection method in the implementation of construction projects.

A number of previous studies have discussed the effectiveness of using coupler joints compared to conventional joints. Research by [4] shows that the rebar coupler method is able to reduce installation time compared to overlap joints in building projects. Another study by [12] states that the use of mechanical couplers in column structure work can speed up the installation of joints, especially in areas with high reinforcement density. Meanwhile, [13] explained that the coupler method is more practical at the installation stage even though it requires additional fabrication processes in the form of threading and cold forging. On the other hand, the results of the study [14] show that the duration of mechanical splice work can be longer than that of lap splice due to the need for tools and additional work stages. The findings show that the effectiveness of the connection method still results in mixed conclusions and is greatly influenced by the characteristics of the work as well as the conditions of the project.

Based on this study, there is still a research gap in the previous research. Most previous studies have focused more on column joint work, cost analysis, or method comparison in general, while research on the comparison of mechanical couplers and lap splice in precast beam joint work based on detailed work duration analysis is still limited. In addition, previous research generally did not

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discuss the stages of work as a whole, starting from fabrication, transfer materials, to installation of connections in the field through direct observation. In fact, each stage of work has different duration characteristics and can affect the effectiveness of the connection method used. Therefore, research is needed that specifically compares the two connection methods based on the duration of actual work in the field in order to obtain a more comprehensive picture of the efficiency of their implementation.

Based on the existing literature, several research gaps remain. Previous studies have primarily focused on structural performance, construction cost, column connection applications, or general comparisons between reinforcement connection methods [4], [12], [13], [14] . However, no previous study has comprehensively compared the construction duration of mechanical coupler and lap splice methods specifically for precast beam joints by evaluating the complete sequence of work, including fabrication, material transfer, and field installation, using direct field observations. Since each construction stage has distinct duration characteristics that collectively influence project efficiency, a comprehensive duration-based comparison under actual construction conditions remains necessary.

Based on the background and identified research gaps, this study addresses the following research questions: (1) How do the construction durations of the mechanical coupler and lap splice methods differ for individual reinforcement connections; (2) How do the construction durations of the mechanical coupler and lap splice methods differ at the beam joint level? (3) Which reinforcement connection method provides greater construction time efficiency under actual field conditions. Align with those research questions, this study aims to analyze and compare the construction duration and time efficiency of mechanical coupler and lap splice methods for precast beam joints under actual field conditions using the PERT approach. The analysis was conducted on the duration of work per reinforcement connection and per beam joint using a comparative quantitative approach and the PERT method to obtain a more realistic estimate of the work time.

To fill the gaps that have been identified before, this study offers several novel contributions to the existing literature. First, it applies the Program Evaluation and Review Technique (PERT) to estimate construction duration based on optimistic, most likely, and pessimistic scenarios. Second, unlike previous studies that mainly evaluated installation duration or column connections, this study assesses construction duration at both the individual reinforcement connection level and the beam joint level, providing a more comprehensive evaluation of construction efficiency. Third, the analysis is based on direct field observations of precast beam construction activities, including fabrication, material transfer, and installation processes under actual construction conditions. These aspects provide a more comprehensive evaluation of construction time efficiency under actual construction conditions than has been reported in previous studies.

2. Materials and Methods

This study employed a descriptive quantitative approach using a comparative research design to compare the construction duration and time efficiency of reinforced concrete beam joints using mechanical couplers and lap splice methods. The research was conducted at the Mitra Plumbon Hospital construction project in Sumedang, West Java, Indonesia. Observations were focused on the seventh-floor beam structure in Zone 1, where both reinforcement connection methods were implemented under actual construction conditions. The study was limited to evaluating the duration and efficiency of beam reinforcement connection work using these two methods.

Research data were obtained through direct observation, interviews, and documentation. Direct observations were conducted to record the duration of each work activity from the beginning to the completion of the reinforcement connection process. Interviews with site engineers, foremen, and construction workers were carried out to obtain technical information regarding work implementation and sequence. Documentation, including construction drawings, project records, and field photographs, was used to support and verify the observational data. The research instruments consisted of a stopwatch for measuring work duration, observation sheets for recording field data, a digital camera for documentation, and Microsoft Excel for data processing.

The observation units were selected using purposive sampling, considering beam joint activities that were actively under construction and allowed all work stages to be directly observed. The observations consisted of four working-day observations for the reinforcement connection analysis

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and eight beam joint observations for each reinforcement connection method in the beam joint duration analysis. Each observation represented one complete work cycle conducted under normal construction conditions by the regular project workforce using standard construction procedures.

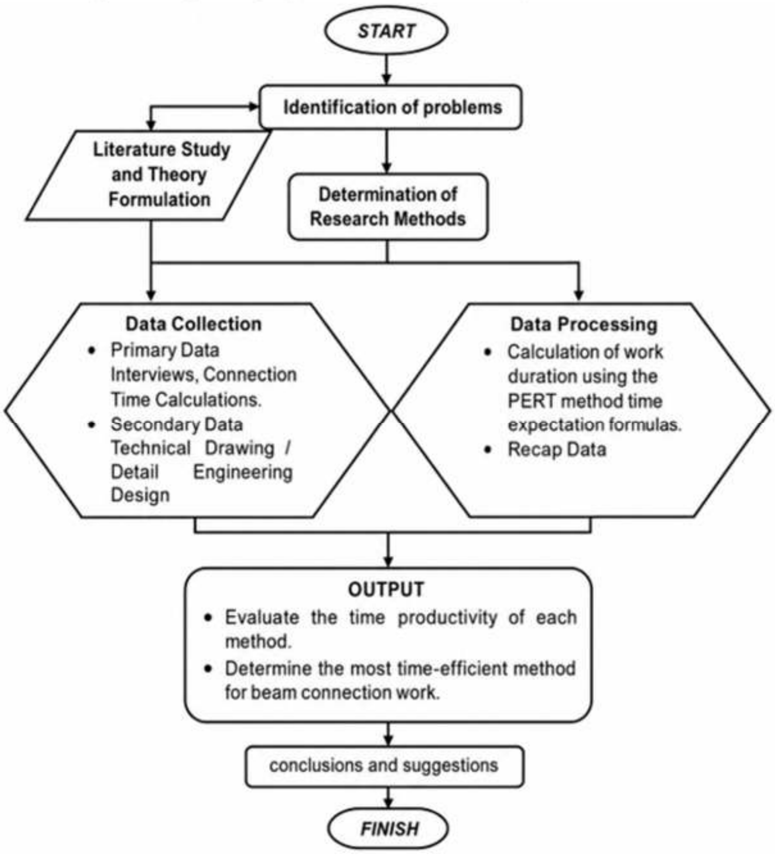

Figure 1. Resarch Flow Chart

The research procedure followed the stages presented in Figure 1. The figure above illustrates the overall research procedure, including problem identification, literature review, data collection, data processing using the PERT method, and evaluation of the construction time efficiency of each reinforcement connection method before drawing the study conclusions. The study began with problem identification and a literature review to establish the theoretical framework and determine the research method. Subsequently, primary and secondary data were collected through field observations, interviews, and project documentation. The observed work durations were then processed using the Program Evaluation and Review Technique (PERT), followed by comparative analysis to evaluate the duration and time efficiency of the two reinforcement connection methods. Finally, the analysis results were interpreted to identify the more time-efficient reinforcement connection method for beam construction.

The duration data were analyzed quantitatively using Microsoft Excel by calculating the expected duration, average duration, and time efficiency for each reinforcement connection method. The Program Evaluation and Review Technique (PERT) was adopted because construction activities are inherently subject to uncertainty arising from variations in worker performance, equipment utilization, material handling, and field conditions. Unlike deterministic estimation methods, PERT incorporates three time estimates—optimistic (a), most likely (m), and pessimistic (b)—to obtain a more realistic estimate of the expected construction duration. The expected time (ET) was calculated using the following equation:

$$ET = \frac{a + 4m + b}{6}$$

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To ensure calculation consistency, all observed durations recorded in hours, minutes, and seconds were first converted into seconds before calculating the expected time, average duration, and efficiency percentage. The calculated results were subsequently converted back into minutes and seconds to facilitate interpretation and comparison between the mechanical coupler and lap splice methods.

To improve data quality, all observations were conducted using the same measurement procedures and observation instruments throughout the study. The start and end points of each work activity were determined using consistent operational definitions, and each observation was performed directly under actual construction conditions. In addition, the recorded observations were cross-checked with the site supervisor and foreman to ensure that the observed work sequence accurately represented the standard construction procedure. These procedures were implemented to enhance the validity and reliability of the observational data.

3. Results and Discussions

3.1. Analysis of Reinforcement Connection

3.1.1. Mechanical Coupler Connection Analysis

The analysis of the reinforcement connection was conducted by calculating the average duration required to complete a single reinforcement connection point. Each connection was observed from the preparation process until the connection was fully installed according to the method used. In the mechanical coupler method, the duration of a single joint is calculated from the moment the reinforcement ends are ready for installation until the coupler is fully locked. The following is an example of data processing and the calculation of expected time for mechanical coupled reinforcement joint work, as shown in Table 1.

Table 1. Analysis of Reinforcement Coupler Joint Duration

DAY 1 ACTIVITIES AND DURATION OF CONNECTION WORK					
METHOD	ACTIVITY CODE	OPTIMISTIC DURATION (a)	REALISTIC DURATION (m)	PESIMISTIC DURATION (b)	EXPECTED TIME
COUPLER	CUTTING	00:00:19	00:00:23	00:00:29	00:00:23
	COLD FORGING	00:00:10	00:00:13	00:00:13	00:00:12
	THREADING	00:01:11	00:01:12	00:01:21	00:01:13
	TRANSFER MATERIAL	00:02:25	00:02:38	00:03:17	00:02:43
	CONNECTION INSTALL	00:01:08	00:01:15	00:01:47	00:01:19
				TOTAL	00:05:51
DAY 2 ACTIVITIES AND DURATION OF CONNECTION WORK					
METHOD	ACTIVITY CODE	OPTIMISTIC DURATION (a)	REALISTIC DURATION (m)	PESIMISTIC DURATION (b)	EXPECTED TIME
COUPLER	CUTTING	00:00:20	00:00:22	00:00:27	00:00:23
	COLD FORGING	00:00:11	00:00:12	00:00:16	00:00:12
	THREADING	00:01:12	00:01:14	00:01:19	00:01:15
	TRANSFER MATERIAL	00:02:30	00:02:30	00:03:22	00:02:39
	CONNECTION INSTALL	00:01:13	00:01:19	00:01:33	00:01:20
				TOTAL	00:05:49

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DAY 3 ACTIVITIES AND DURATION OF CONNECTION WORK					
METHOD	ACTIVITY CODE	OPTIMISTIC DURATION (a)	REALISTIC DURATION (m)	PESIMISTIC DURATION (b)	EXPECTED TIME
COUPLER	CUTTING	00:00:19	00:00:19	00:00:28	00:00:21
	COLD FORGING	00:00:10	00:00:14	00:00:19	00:00:14
	THREADING	00:01:11	00:01:12	00:01:22	00:01:14
	TRANSFER MATERIAL	00:02:16	00:02:32	00:02:48	00:02:32
	CONNECTION INSTALL	00:01:09	00:01:13	00:01:40	00:01:17
				TOTAL	00:05:37

DAY 4 ACTIVITIES AND DURATION OF CONNECTION WORK					
METHOD	ACTIVITY CODE	OPTIMISTIC DURATION (a)	REALISTIC DURATION (m)	PESIMISTIC DURATION (b)	EXPECTED TIME
COUPLER	CUTTING	00:00:19	00:00:22	00:00:25	00:00:22
	COLD FORGING	00:00:09	00:00:11	00:00:14	00:00:11
	THREADING	00:01:11	00:01:16	00:01:17	00:01:15
	TRANSFER MATERIAL	00:02:34	00:02:38	00:04:03	00:02:52
	CONNECTION INSTALL	00:01:10	00:01:14	00:01:27	00:01:16
				TOTAL	00:05:55

$$Average = \frac{Duration\ H1 + Duration\ H2 + Duration\ H3 + Duration\ H4}{4}$$

$$Average = \frac{5{,}51 + 5{,}49 + 5{,}37 + 5{,}55}{4}$$

$$Average = 05{:}48\ minutes$$

$$Average = 348\ \text{seconds}$$

Based on the results of the average duration calculation for each reinforcement joint using the mechanical coupler method, an average time of 5 minutes and 48 seconds was obtained for each reinforcement joint. This value was derived from observations over four workdays, with durations of 5 minutes 51 seconds, 5 minutes 49 seconds, 5 minutes 37 seconds, and 5 minutes 55 seconds, respectively. The data indicates that the time differences between observations are relatively small, suggesting that the reinforcement connection process using couplers exhibits a sufficiently high level of consistency on-site.

3.1.2. Lap splice Connection Analysis

The reinforcement joint analysis was conducted by calculating the average duration required to complete a single reinforcement joint. Each joint was observed from the preparation process until the joint was fully installed according to the method used. In the lap splice method, a single joint is calculated starting from when two reinforcement bars are positioned to lap splice, their lap lengths are adjusted, until they are fully tied using wire, as shown in Table 2.

Table 2. Analysis of Lap splice Reinforcement Joint Duration

DAY 1 ACTIVITIES AND DURATION OF CONNECTION WORK					
METHOD	ACTIVITY CODE	OPTIMISTIC DURATION (a)	REALISTIC DURATION (m)	PESIMISTIC DURATION (b)	EXPECTED TIME
LAP SPLICE	CUTTING	00:00:21	00:00:28	00:00:28	00:00:27
	TRANSFER MATERIAL	00:02:25	00:02:38	00:03:17	00:02:43
	CONNECTION INSTALL	00:01:50	00:02:12	00:02:48	00:02:14
				TOTAL	00:05:24

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DAY 2 ACTIVITIES AND DURATION OF CONNECTION WORK					
METHOD	ACTIVITY CODE	OPTIMISTIC DURATION (a)	REALISTIC DURATION (m)	PESIMISTIC DURATION (b)	EXPECTED TIME
LAP SPLICE	CUTTING	00:00:21	00:00:24	00:00:27	00:00:24
	TRANSFER MATERIAL	00:02:30	00:02:30	00:03:22	00:02:39
	CONNECTION INSTALL	00:01:51	00:02:13	00:02:30	00:02:12
				TOTAL	00:05:15
DAY 3 ACTIVITIES AND DURATION OF CONNECTION WORK					
METHOD	ACTIVITY CODE	OPTIMISTIC DURATION (a)	REALISTIC DURATION (m)	PESIMISTIC DURATION (b)	EXPECTED TIME
LAP SPLICE	CUTTING	00:00:21	00:00:23	00:00:28	00:00:24
	TRANSFER MATERIAL	00:02:16	00:02:32	00:02:48	00:02:32
	CONNECTION INSTALL	00:01:45	00:02:14	00:02:41	00:02:14
				TOTAL	00:05:10
DAY 4 ACTIVITIES AND DURATION OF CONNECTION WORK					
METHOD	ACTIVITY CODE	OPTIMISTIC DURATION (a)	REALISTIC DURATION (m)	PESIMISTIC DURATION (b)	EXPECTED TIME
LAP SPLICE	CUTTING	00:00:20	00:00:21	00:00:25	00:00:22
	TRANSFER MATERIAL	00:02:34	00:02:38	00:04:03	00:02:52
	CONNECTION INSTALL	00:01:55	00:02:13	00:02:22	00:02:12
				TOTAL	00:05:25

$$Average = \frac{Duration\ H1 + Duration\ H2 + Duration\ H3 + Duration\ H4}{4}$$

$$Average = \frac{5{,}24 + 5{,}15 + 5{,}10 + 5{,}25}{4}$$

$$Average = 05{:}18\ minutes$$

$$Average = 318\ seconds$$

Based on the results of the average duration calculation per reinforcement joint using the lap splice method, an average time of 5 minutes and 18 seconds was obtained for each reinforcement joint. This value was derived from observations over four workdays, with durations of 5 minutes 24 seconds, 5 minutes 15 seconds, 5 minutes 10 seconds, and 5 minutes 25 seconds, respectively. The data indicates that the work durations across each observation differed only slightly, suggesting that the lap splice process was carried out with reasonable consistency on-site.

3.1.3. Descriptive Statistics of Reinforcement Connection Duration

Table 3. Descriptive Statistics of Reinforcement Connection Duration

Method	n	Mean (s)	SD (s)	Minimum (s)
Mechanical Coupler	4	348	**8.25**	337
Lap splice	4	318	**6.98**	310

To provide a clearer description of the observed work durations, descriptive statistics were calculated for each reinforcement connection method, as presented in Table 3. The mechanical coupler method produced an average duration of 348 s (SD = 8.25 s), while the lap splice method required an average duration of 318 s (SD = 6.98 s). The relatively small standard deviation values indicate that the observed durations varied only slightly across the four observation days, suggesting that the field measurements were sufficiently consistent for comparative analysis.

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3.1.4. Efficiency of Reinforcement Connection

The efficiency of the reinforcement connection was evaluated by comparing the average work duration between the mechanical coupler and lap splice methods. The percentage of time efficiency was calculated using the following equation:

$$Efficiency = \frac{T_{MC} - T_{LS}}{T_{MC}} \times 100\%$$

where:

- T_{MC}= Average duration using the mechanical coupler method
- T_{LS}= Average duration using the lap splice method

The calculation is presented as follows:
Mechanical coupler duration = 5 minutes 48 seconds = 348 s
Lap splice duration = 5 minutes 18 seconds = 318 s

$$Efficiency = \frac{348 - 318}{348} \times 100\%$$

$$Efficiency = \frac{30}{348} \times 100\%$$

$$Efficiency = 8.62\%$$

The calculation results indicate that the lap splice method reduces the reinforcement connection duration by 30 seconds, corresponding to a time efficiency of 8.62% compared with the mechanical coupler method. Although the difference for a single reinforcement connection is relatively small, the accumulated time savings become significant when a large number of reinforcement connections are installed throughout the project.

3.2. Analysis Duration Beam Joint

3.2.1. Mechanical Coupler Connection Analysis

In addition to being calculated per reinforcing joint, the data was also analyzed based on each beam joint. The beam joint in question refers to a single intersection point or a single connection zone on a beam element where multiple upper and lower reinforcing bars are present and require comprehensive completion. Calculations per beam joint are performed by summing the total time required for reinforcement connection work within a single beam joint until the connection work at that point is completed [15], [16]. This analysis is important because, in field implementation, the completion of work is typically targeted based on a single structural element or joint point, not just a single reinforcement bar as shown in Table 4.

Table 4. Analysis of Duration Per Beam Joint Using the Mechanical Coupler Method

MECHANICAL COUPLER JOINT WORK DURATION					
AS	ACTIVITY CODE	OPTIMISTIC DURATION (a)	REALISTIC DURATION (m)	PESIMISTIC DURATION (b)	EXPECTED TIME
AS 12D	CUTTING	00:00:19	00:00:23	00:00:29	00:04:40
	COLD FORGING	00:00:10	00:00:13	00:00:13	00:02:30
	THREADING	00:01:11	00:01:12	00:01:21	00:14:40
	TRANSFER MATERIAL	00:02:25	00:02:38	00:03:17	00:02:43
	CONNECTION INSTALL	00:01:08	00:01:13	00:01:47	00:15:34
				TOTAL	00:40:07
AS 10D	CUTTING	00:00:19	00:00:23	00:00:29	00:04:40
	COLD FORGING	00:00:10	00:00:13	00:00:13	00:02:30
	THREADING	00:01:11	00:01:12	00:01:21	00:14:40
	TRANSFER MATERIAL	00:02:25	00:02:38	00:03:17	00:02:43
	CONNECTION INSTALL	00:01:13	00:01:19	00:01:33	00:16:04
				TOTAL	00:40:37

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AS	ACTIVITY CODE	OPTIMISTIC DURATION (a)	REALISTIC DURATION (m)	PESIMISTIC DURATION (b)	EXPECTED TIME
AS 8B	CUTTING	00:00:20	00:00:22	00:00:27	00:04:30
	COLD FORGING	00:00:11	00:00:12	00:00:16	00:02:30
	THREADING	00:01:12	00:01:14	00:01:19	00:14:54
	TRANSFER MATERIAL	00:02:30	00:02:30	00:03:22	00:02:39
	CONNECTION INSTALL	00:01:17	00:01:19	00:01:33	00:16:12
				TOTAL	00:40:45
AS 8D	CUTTING	00:00:20	00:00:22	00:00:27	00:04:30
	COLD FORGING	00:00:11	00:00:12	00:00:16	00:02:30
	THREADING	00:01:12	00:01:14	00:01:19	00:14:54
	TRANSFER MATERIAL	00:02:30	00:02:30	00:03:22	00:02:39
	CONNECTION INSTALL	00:01:13	00:01:13	00:01:25	00:15:00
				TOTAL	00:39:33
AS	ACTIVITY CODE	OPTIMISTIC DURATION (a)	REALISTIC DURATION (m)	PESIMISTIC DURATION (b)	EXPECTED TIME
AS 6B	CUTTING	00:00:19	00:00:19	00:00:28	00:04:06
	COLD FORGING	00:00:10	00:00:14	00:00:19	00:02:50
	THREADING	00:01:11	00:01:12	00:01:22	00:14:42
	TRANSFER MATERIAL	00:02:16	00:02:32	00:02:48	00:02:32
	CONNECTION INSTALL	00:01:09	00:01:12	00:01:40	00:15:14
				TOTAL	00:39:24
AS 6D	CUTTING	00:00:19	00:00:19	00:00:28	00:04:06
	COLD FORGING	00:00:10	00:00:14	00:00:19	00:02:50
	THREADING	00:01:11	00:01:12	00:01:22	00:14:42
	TRANSFER MATERIAL	00:02:16	00:02:32	00:02:48	00:02:32
	CONNECTION INSTALL	00:01:12	00:01:17	00:01:23	00:15:26
				TOTAL	00:39:36
AS	ACTIVITY CODE	OPTIMISTIC DURATION (a)	REALISTIC DURATION (m)	PESIMISTIC DURATION (b)	EXPECTED TIME
AS 8E	CUTTING	00:00:19	00:00:22	00:00:25	00:04:24
	COLD FORGING	00:00:09	00:00:11	00:00:14	00:02:14
	THREADING	00:01:11	00:01:16	00:01:17	00:15:04
	TRANSFER MATERIAL	00:02:34	00:02:38	00:04:03	00:02:52
	CONNECTION INSTALL	00:01:13	00:01:14	00:01:27	00:15:12
				TOTAL	00:39:45
AS 6E	CUTTING	00:00:19	00:00:22	00:00:25	00:04:24
	COLD FORGING	00:00:09	00:00:11	00:00:14	00:02:14
	THREADING	00:01:11	00:01:16	00:01:17	00:15:04
	TRANSFER MATERIAL	00:02:34	00:02:38	00:04:03	00:02:52
	CONNECTION INSTALL	00:01:10	00:01:14	00:01:24	00:15:00
				TOTAL	00:39:34

$$Average = \frac{\text{AS 12D} + \text{AS 10D} + \text{AS 8B} + \text{AS 8D} + \text{AS 6B} + \text{AS 6D} + \text{AS 8E} + \text{AS 6E}}{8}$$

$$Average = \frac{40{,}07 + 40{,}37 + 40{,}45 + 39{,}33 + 39{,}24 + 39{,}36 + 39{,}45 + 39{,}34}{8}$$

$$Average = 39{:}55\ minutes$$

$$Average = 2.395\ seconds$$

Based on the average calculation of the duration of beam joint work using the mechanical coupler method, an average time of 39 minutes and 55 seconds per beam joint was obtained. This value was derived from eight observed samples of joint work, comprising various installation areas

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or locations. The calculation results indicate that the work duration for the coupler method is relatively stable, as the time differences between samples are not significant. This indicates that the work process was carried out using nearly identical methods and work stages at each beam joint.

3.2.2. Lap splice Connection Analysis

In addition to being calculated per reinforced joint, the data was also analyzed based on each beam joint. The beam joint in question refers to a single intersection point or a single connection zone on a beam element where several upper and lower reinforcing bars are present and require comprehensive completion. Calculations per beam joint are performed by summing the total work time for each reinforcement joint within a single beam joint until the joint work at that point is completed. This analysis is important because, in field implementation, work completion is typically targeted based on a single structural element or joint point, not just a single reinforcement bar as shown in Table 5.

Table 5. Duration Analysis Using the Lap Splice Method

LAP SPLICE JOINT WORK DURATION					
AS	ACTIVITY CODE	OPTIMISTIC DURATION (a)	REALISTIC DURATION (m)	PESIMISTIC DURATION (b)	EXPECTED TIME
AS 13E	CUTTING	00:00:21	00:00:28	00:00:28	00:05:22
	TRANSFER MATERIAL	00:02:25	00:02:38	00:03:17	00:02:43
	CONNECTION INSTALL	00:01:50	00:02:12	00:02:48	00:26:52
				TOTAL	00:34:57
AS	ACTIVITY CODE	OPTIMISTIC DURATION (a)	REALISTIC DURATION (m)	PESIMISTIC DURATION (b)	EXPECTED TIME
AS 13F	CUTTING	00:00:21	00:00:28	00:00:28	00:05:22
	TRANSFER MATERIAL	00:02:25	00:02:38	00:03:17	00:02:43
	CONNECTION INSTALL	00:02:08	00:02:18	00:02:26	00:27:32
				TOTAL	00:35:37
AS	ACTIVITY CODE	OPTIMISTIC DURATION (a)	REALISTIC DURATION (m)	PESIMISTIC DURATION (b)	EXPECTED TIME
AS 12E	CUTTING	00:00:21	00:00:24	00:00:27	00:04:48
	TRANSFER MATERIAL	00:02:30	00:02:30	00:03:22	00:02:39
	CONNECTION INSTALL	00:01:51	00:02:16	00:02:29	00:26:48
				TOTAL	00:34:15
AS	ACTIVITY CODE	OPTIMISTIC DURATION (a)	REALISTIC DURATION (m)	PESIMISTIC DURATION (b)	EXPECTED TIME
AS 12F	CUTTING	00:00:21	00:00:24	00:00:27	00:04:48
	TRANSFER MATERIAL	00:02:30	00:02:30	00:03:22	00:02:39
	CONNECTION INSTALL	00:02:04	00:02:12	00:02:30	00:26:44
				TOTAL	00:34:11
AS	ACTIVITY CODE	OPTIMISTIC DURATION (a)	REALISTIC DURATION (m)	PESIMISTIC DURATION (b)	EXPECTED TIME
AS 11E	CUTTING	00:00:21	00:00:23	00:00:28	00:04:42
	TRANSFER MATERIAL	00:02:16	00:02:32	00:02:48	00:02:32
	CONNECTION INSTALL	00:01:45	00:02:23	00:02:41	00:27:56
				TOTAL	00:35:10
AS	ACTIVITY CODE	OPTIMISTIC DURATION (a)	REALISTIC DURATION (m)	PESIMISTIC DURATION (b)	EXPECTED TIME
AS 11F	CUTTING	00:00:21	00:00:23	00:00:28	00:04:42
	TRANSFER MATERIAL	00:02:16	00:02:32	00:02:48	00:02:32
	CONNECTION INSTALL	00:01:57	00:02:13	00:02:25	00:26:28
				TOTAL	00:33:42

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AS	ACTIVITY CODE	OPTIMISTIC DURATION (a)	REALISTIC DURATION (m)	PESIMISTIC DURATION (b)	EXPECTED TIME
AS 10E	CUTTING	00:00:20	00:00:21	00:00:25	00:04:18
	TRANSFER MATERIAL	00:02:34	00:02:38	00:04:03	00:02:52
	CONNECTION INSTALL	00:01:55	00:02:13	00:02:18	00:26:10
				TOTAL	00:33:20
AS	ACTIVITY CODE	OPTIMISTIC DURATION (a)	REALISTIC DURATION (m)	PESIMISTIC DURATION (b)	EXPECTED TIME
AS 11H	CUTTING	00:00:20	00:00:21	00:00:25	00:04:18
	TRANSFER MATERIAL	00:02:34	00:02:38	00:04:03	00:02:52
	CONNECTION INSTALL	00:02:01	00:02:14	00:02:22	00:26:38
				TOTAL	00:33:48

$$Average = \frac{\text{AS13E} + \text{AS13F} + \text{AS12E} + \text{AS12F} + \text{AS11E} + \text{AS11F} + \text{AS10E} + \text{AS11H}}{8}$$

$$Average = \frac{34{,}57 + 35{,}37 + 34{,}15 + 34{,}11 + 35{,}10 + 33{,}42 + 33{,}20 + 33{,}48}{8}$$

$$Average = 34{:}22\ minutes$$

$$Average = 2.062\ seconds$$

Based on the average duration calculations for each beam joint using the lap splice method, an average time of 34 minutes and 22 seconds or 2.062 seconds was obtained for each beam joint. This value was derived from eight observation samples at several beam joint points, namely AS13E, AS13F, AS12E, AS12F, AS11E, AS11F, AS10E, and AS11H. The calculation results indicate that the work duration using the lap splice method is relatively stable at each beam joint, suggesting that the construction process is sufficiently consistent on-site.

3.2.3. Mechanical Coupler Connection Analysis

Table 6. Descriptive Statistics of Beam Joint Construction Duration

Method	**n**	**Mean (s)**	**SD (s)**	**Minimum (s)**
Mechanical Coupler	8	2,395	**31.06**	2,364
Lap splice	8	2,062	**47.69**	2,000

Table 6 presents the descriptive statistics of beam joint construction duration for both reinforcement connection methods. The mechanical coupler method required an average duration of 2,395 s (SD = 31.06 s), whereas the lap splice method required an average duration of 2,062 s (SD = 47.69 s). Although the lap splice method exhibited slightly greater variability in construction duration, both methods showed relatively small standard deviations compared with their respective mean values, indicating that the observed beam joint construction durations were sufficiently consistent throughout the field observations.

3.2.4. Efficiency of Duration Beam Joint

The efficiency of beam joint construction was determined by comparing the total duration required to complete one beam joint using the **mechanical coupler** and **lap splice** methods. The efficiency was calculated using the same equation:

$$Efficiency = \frac{T_{MC} - T_{LS}}{T_{MC}} \times 100\%$$

The calculation is presented as follows:

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Mechanical coupler duration = 39 minutes 55 seconds = 2,395 s
Lap splice duration = 34 minutes 22 seconds = 2,062 s

$$Efficiency = \frac{2395 - 2062}{2395} \times 100\%$$
$$Efficiency = \frac{333}{2395} \times 100\%$$
$$Efficiency = 13.90\%$$

The results show that the lap splice method shortens the beam joint construction duration by 5 minutes 33 seconds, corresponding to a time efficiency of 13.90% compared with the mechanical coupler method.

3.3. Summary Comparison

The comparative results presented in Table 5 provide the basis for discussing the advantages and limitations of each reinforcement connection method under actual construction conditions.

Table 7. Summary Comparison of Construction Duration and Time Efficiency Between Mechanical Coupler and Lap Splice Methods

Analysis	Mechanical Coupler	Lap Splice	Difference	Time Efficiency
Reinforcement connection	348 s	318 s	30 s	8.62%
Beam joint	2,395 s	2,062 s	333 s	13.90%

Table 7 summarizes the overall comparison of construction duration between the mechanical coupler and lap splice methods at both the reinforcement connection and beam joint levels. The lap splice method consistently demonstrated shorter construction durations than the mechanical coupler method. The resulting time efficiencies reached 8.62% for individual reinforcement connections and increased to 13.90% for beam joint construction. These findings indicate that although the duration difference for a single reinforcement connection is relatively small, the cumulative time savings become more substantial when the analysis is conducted at the beam joint level, providing a clearer representation of the practical implications for construction project scheduling.

3.4. Discussions

Several previous studies have demonstrated that the selection of reinforcement connection methods influences construction time, work efficiency, and constructability. Murtadho et al. [12] reported that the use of mechanical couplers in reinforced concrete columns can improve construction efficiency, particularly in structural elements with high reinforcement density, by reducing installation time. Likewise, other study by Ramanjaneyuhu & Aparna [17] found that although the fabrication process of coupler connections requires additional preparation, the installation stage can be completed more efficiently than conventional lap splice connections. Furthermore, Natalia et al and Widjaja et al [18], [19] who emphasized that the selection of reinforcement connection methods should consider not only construction duration but also the characteristics of the structural element and project implementation requirements.

The findings of this study indicate that the comparison between the mechanical coupler and lap splice methods depends on the level of analysis performed. At the activity level, the lap splice method required a shorter fabrication duration because the reinforcement only needed to be cut to the specified length before installation. In contrast, the mechanical coupler method required additional fabrication processes, including cold forging and threading, before installation could begin. However, during the installation stage, the mechanical coupler method required less assembly time because the reinforcement bars only needed to be aligned and tightened using the coupler, whereas the lap splice method required reinforcement positioning followed by manual wire tying.

It is important to distinguish between installation duration and total work duration. Installation duration refers only to the time required to connect the reinforcement once all preparation activities

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have been completed. In contrast, total work duration includes the entire construction sequence, consisting of reinforcement cutting, cold forging, threading (for the coupler method), material transfer, and final installation. Consequently, although the mechanical coupler method provides a relatively faster installation process, its additional fabrication activities increase the overall work duration. This explains why the lap splice method demonstrated a shorter total construction duration despite requiring a longer installation process.

For individual reinforcement connections, the lap splice method required an average duration of 318 seconds (5 min 18 s), compared with 348 seconds (5 min 48 s) for the mechanical coupler method, representing a time efficiency of 8.62%. The difference of approximately 30 seconds per connection is relatively small, indicating that both methods provide comparable performance when evaluated at a single reinforcement connection point. However, when the analysis was expanded to the beam-joint level, the accumulated effect of the additional fabrication activities became more evident. The average duration for one beam joint was 2,062 seconds (34 min 22 s) using the lap splice method and 2,395 seconds (39 min 55 s) using the mechanical coupler method, resulting in a time efficiency of 13.90% or approximately 5 minutes and 33 seconds per beam joint.

The present findings partially differ from those reported by Murtadho et al. [12], who concluded that mechanical couplers could shorten reinforcement installation time. This difference is likely attributable to differences in the observed structural elements and work scope. Their study focused primarily on reinforced concrete columns with dense reinforcement arrangements, where the simplified installation procedure of mechanical couplers provided greater benefits. In contrast, the present study evaluated reinforced concrete beam joints, where the total work duration was influenced more substantially by the additional fabrication processes required for couplers, namely cold forging and threading. Therefore, although the installation process itself was relatively efficient, the accumulated preparation time resulted in a longer overall construction duration.

These findings are consistent with previous studies emphasizing that constructability should not be evaluated solely from installation speed but from the entire construction process [5], [8], [20]. From a constructability perspective, lap splice connections offer advantages in terms of simplicity because they require fewer fabrication stages. Conversely, mechanical couplers improve reinforcement arrangement by eliminating lap lengths, thereby reducing reinforcement congestion within beam joints. This condition provides additional working space for reinforcement placement and concrete casting, particularly in heavily reinforced structural members, which may contribute to better construction quality despite requiring longer preparation time {Formatting Citation}.

From a practical perspective, the results suggest that the selection of reinforcement connection methods should be adapted to project objectives. For projects prioritizing rapid construction progress or fast-track schedules, the lap splice method may be preferable because it provides shorter total work duration. Conversely, for high-rise buildings or structural members with congested reinforcement layouts, the mechanical coupler method remains advantageous because it produces a neater reinforcement configuration, minimizes reinforcement congestion, and facilitates reinforcement placement and concrete casting. Therefore, construction practitioners should consider both construction efficiency and constructability when selecting reinforcement connection methods rather than relying solely on installation speed.

This study has several limitations. First, the observations were conducted on a single construction project and were limited to beam-joint reinforcement work on the seventh floor of the Mitra Plumbon Hospital project. Consequently, the findings may not fully represent other structural elements or different project characteristics. Second, the comparison focused primarily on construction duration and did not include other important aspects such as construction cost, labor productivity, structural performance, or long-term maintenance. Future studies are therefore recommended to integrate time, cost, quality, and structural performance evaluations to provide a more comprehensive assessment of reinforcement connection methods.

4. Conclusions

This study demonstrates that the lap splice method provides a shorter total construction duration than the mechanical coupler method for both reinforcement connection and beam joint work, thereby

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directly answering the research objective of comparing the time efficiency of the two reinforcement connection methods. The average duration for a single reinforcement connection was 318 seconds (5 min 18 s) using the lap splice method and 348 seconds (5 min 48 s) using the mechanical coupler method, representing a time efficiency of 8.62%. At the beam-joint level, the average construction duration was 2,062 seconds (34 min 22 s) for the lap splice method and 2,395 seconds (39 min 55 s) for the mechanical coupler method, resulting in a time efficiency of 13.90%.

From a practical perspective, the lap splice method is more suitable for projects prioritizing shorter overall construction duration, whereas the mechanical coupler method remains advantageous for structural elements with congested reinforcement because it provides neater reinforcement arrangements and facilitates installation. Therefore, the selection of reinforcement connection methods should consider both construction efficiency and project characteristics rather than construction duration alone.

Scientifically, this study contributes by demonstrating that the PERT method can be effectively applied to evaluate and compare the productivity and time efficiency of reinforcement connection methods at both the individual reinforcement connection and beam-joint levels, providing an objective basis for construction performance evaluation.

This study was limited to observations conducted on beam reinforcement work within a single construction project and focused only on construction duration. Future studies are therefore recommended to integrate construction cost, structural performance, labor productivity, Life Cycle Cost (LCC), and Building Information Modeling (BIM) to provide a more comprehensive evaluation of reinforcement connection methods under different project conditions.

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