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## Optimization of High Early-Strength Concrete Mix Design for Structural Applications in the BJ. Habibie Stadium Construction Project

Risman Firman<sup>1\*</sup>, Joey Limbongan<sup>2</sup>, Yanny Febry Fitriani Sofyan<sup>3</sup>, Munadrah<sup>4</sup>, Syahrul Satar<sup>5</sup>,  
Ahmad Tamsil Yunus<sup>6</sup>, Andi Widiyarsari Maruddani<sup>7</sup>

<sup>1\*,2,3,4,5,6,7</sup>Departement of Civil Engineering, Institut Teknologi Bacharuddin Jusuf Habibie

Email : <sup>1\*</sup>[risman@ith.ac.id](mailto:risman@ith.ac.id), <sup>2</sup>[joeyl@ith.ac.id](mailto:joeyl@ith.ac.id), <sup>3</sup>[yannyfebryfs@ith.ac.id](mailto:yannyfebryfs@ith.ac.id), <sup>4</sup>[munadrah@ith.ac.id](mailto:munadrah@ith.ac.id),  
<sup>5</sup>[rulsatar@ith.ac.id](mailto:rulsatar@ith.ac.id), <sup>6</sup>[tamsil@ith.ac.id](mailto:tamsil@ith.ac.id), <sup>7</sup>[maruddani@ith.ac.id](mailto:maruddani@ith.ac.id)

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### ABSTRACT

This study investigates the application of high early-strength concrete (HESC) to accelerate the construction of the west tribune at BJ. Habibie Stadium, which underwent total demolition during a critical project phase. The research employed an experimental method to evaluate the feasibility of materials and optimize the mix design, beginning with small-scale trial mixes at the batching plant and validating the effectiveness of predefined quality control procedures. Aggregate testing was performed on coarse and fine aggregates, including analysis of colloid content, fineness modulus, water absorption, moisture content, and specific gravity. Mix design aimed to achieve a target strength of 30 MPa within 7-day using a water-cement ratio of 0.33 and chemical admixtures (retarder and superplasticizer). Concrete samples were tested for compressive strength at 3 and 7 days. Results showed the 7-day average compressive strength reached 35.19 MPa, confirming the effectiveness of the HESC mix for fast-track construction. Early strength gain was supported by good aggregate gradation and chemical admixture synergy, allowing earlier formwork removal and structural progression. This study concludes that the adoption of optimized HESC provides a viable solution for time-constrained infrastructure projects.

## 1. Introduction

The implementation of infrastructure development in large-scale projects often faces various challenges influenced by unpredictable field dynamics. These challenges include time constraints, changing site conditions, and the need to ensure that construction quality and safety are maintained. A concrete example of such challenges occurred during the rehabilitation and renovation project of Gelora BJ. Habibie Stadium. Initially, the plan for the west stand was to retain the existing structure; however, as evaluations progressed and construction developed,



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a decision was made to carry out a complete demolition and rebuild. This decision was taken when the project had already entered a critical phase, with only four months remaining in the contract period, requiring a rapid and efficient change in strategy.

In addressing these time constraints, the use of high early strength concrete became a highly strategic solution. This type of concrete is designed to achieve optimal compressive strength in a much shorter time compared to conventional concrete, allowing for subsequent construction processes, such as formwork removal and the installation of additional structural elements, to proceed earlier without compromising structural quality. High early strength concrete can achieve 100% of its compressive strength in just seven days, making it highly supportive of project progress within a limited timeframe. According to research conducted by A.K. Yasin et al. [1] HESC can reach a compressive strength of 27 MPa within 24 hours, making it an ideal choice for projects operating under tight deadlines.

In addition, the use of low-alkalinity sulfoaluminate cement has been proven effective in producing concrete with rapid hardening and high early strength [2]. The incorporation of additives such as superplasticizers and fly ash has also shown significant improvements in early-age concrete strength [3], [4].

This study aims to evaluate the effectiveness of using high early-strength concrete in accelerating the construction of the west tribune at BJ Habibie Stadium. The main focus includes analyzing the concrete mix design, aggregate characteristics, and the achievement of compressive strength within the targeted timeframe. The findings are expected to contribute to the development of more efficient and effective construction strategies, particularly for projects operating under strict time constraints.

## 2. Research Method

This study adopts an experimental method to examine the effects of varying material compositions on concrete quality. The initial phase involved testing several mix proportions at the batching plant on a limited scale, while also validating the effectiveness of the established quality control procedures. These procedures were developed based on an in-depth review of relevant literature and industry standards, ensuring alignment with proven best practices. This approach enabled a systematic evaluation of mix parameters and provided an empirical foundation for broader implementation in concrete production [5].

## 3. Description and Technical

Aggregate suitability testing covered parameters such as colloid content, fineness modulus, water absorption, moisture content, and specific gravity. These five parameters were selected because they comprehensively represent the physical characteristics of aggregates that directly influence early concrete performance, particularly in the development of early compressive strength [6]. The resulting data were considered sufficient to serve as a foundation for designing a high early-strength concrete mix as they reflect critical aspects such as gradation, inter-particle bonding capability and material interaction with water factor essential to strength development during early curing stages.

The entire process from planning to concrete curing strictly adhered to the Indonesian National Standards (SNI). SNI 7656:2012 was used as the primary reference for designing the concrete mix to meet strength, workability, and environmental resistance parameters. Meanwhile, compressive strength testing was performed using cylindrical specimens measuring 150 mm × 300 mm, and curing procedures followed SNI 4810:2013, which emphasizes the importance of maintaining proper moisture and temperature conditions to optimize strength development and durability of the concrete [7].

## 4. Results and Discussions

### 4.1 Aggregate Suitability Testing

Aggregate testing was carried out to assess the suitability of materials for concrete mixing to achieve optimal results according to the intended mix design [8], [9]. The tests were performed on the aggregates used in the project, including coarse aggregates (3/4" and 1") and fine aggregates.

#### 1. Coarse Aggregate (3/4")

**Table 1.** Research Result of Coarse Aggregate 3/4" Testing (2025)

Item	Unit	Result
Colloid content	%	0,70
Fineness modulus		6,98
Water absorption	%	0,80
Moisture content	%	0,2
Specific gravity		2,62

*Source : Results of Laboratory Testing*

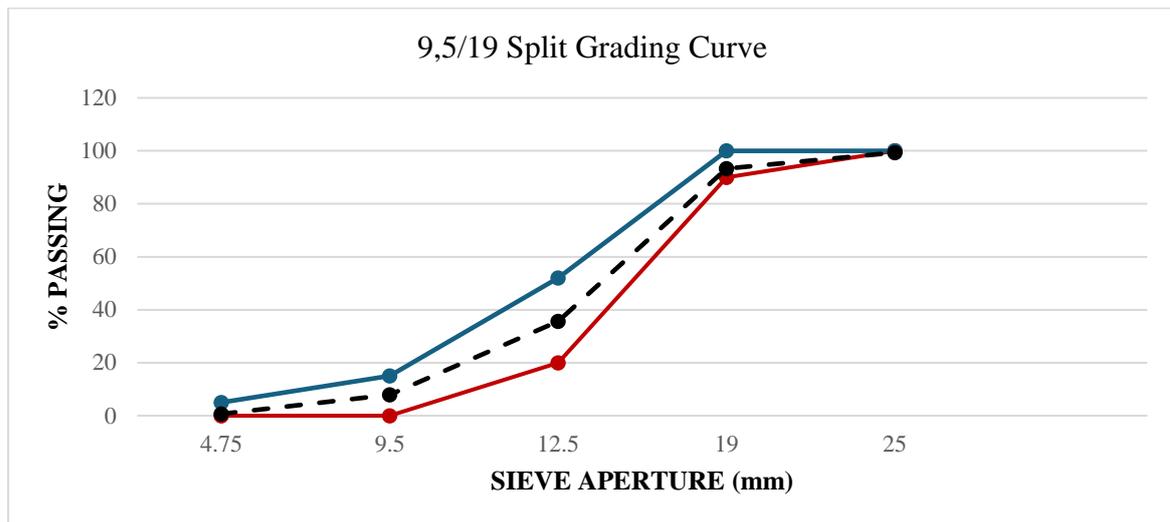
The results show that the coarse aggregate has a fineness modulus of 6.98, indicating a coarse texture suitable for high-strength structural concrete. The water absorption rate of 0.80% is relatively low, suggesting that the aggregate will not absorb excessive moisture, thereby helping maintain the designed water-cement ratio. A specific gravity value of 2.62 reflects good aggregate density, which supports the compressive strength of concrete. Physical characteristics such as density and water absorption have a significant impact on concrete strength [10].

**Table 2.** Research Result of Sieve Analysis (2025)

Sieve aperture (mm)	Retained mass (gram)	% retained	% passing
25	10	0,67	99,33
19	100	6,67	93,33
12,5	965	64,33	35,67
9,7	1382	92,13	7,87
4,75	1490	99,33	0,67
PAN	1500		

*Source : Results of Laboratory Testing*

The particle size distribution in Table 2 shows that the majority of the aggregate is retained on the 12.5 mm sieve (64.33%), with smaller amounts retained on the 19 mm (6.67%) and 9.7 mm (92.13%) sieves. This indicates a good and continuous gradation, which is essential for achieving high concrete density and reducing air voids. Well-graded aggregates contribute significantly to the improvement of both the compressive and tensile strength of concrete [11].



Source : The Results at the Laboratory

**Figure 1.** Research Result Split Grading Curve (2025)

Figure 1 illustrates a continuous (well-graded) grading curve, indicating that the aggregate has a balanced particle size distribution. This favorable gradation allows smaller particles to fill the voids between larger ones, resulting in denser and stronger concrete. According to a study by Abadel et al. [11] optimal aggregate gradation enhances the compressive strength and durability of concrete, particularly in high-performance concrete applications.

Based on the physical data and gradation analysis of the 3/4” coarse aggregate (9.5–19 mm), it can be concluded that this aggregate meets the requirements for use in high-strength structural concrete. The favorable physical properties and optimal particle size distribution support the achievement of high compressive strength and overall concrete durability. These findings are consistent with recent studies emphasizing the importance of aggregate characteristics and gradation in determining concrete quality [10], [11], [12].

1. Coarse Aggregate (1")

**Table 3.** Research Result of Coarse Aggregate 1” Testing (2025)

Item	Unit	Result
Colloid content	%	0,30
Fineness modulus		7,60
Water absorption	%	0,55
Moisture content	%	0,10
Specific gravity		2,63

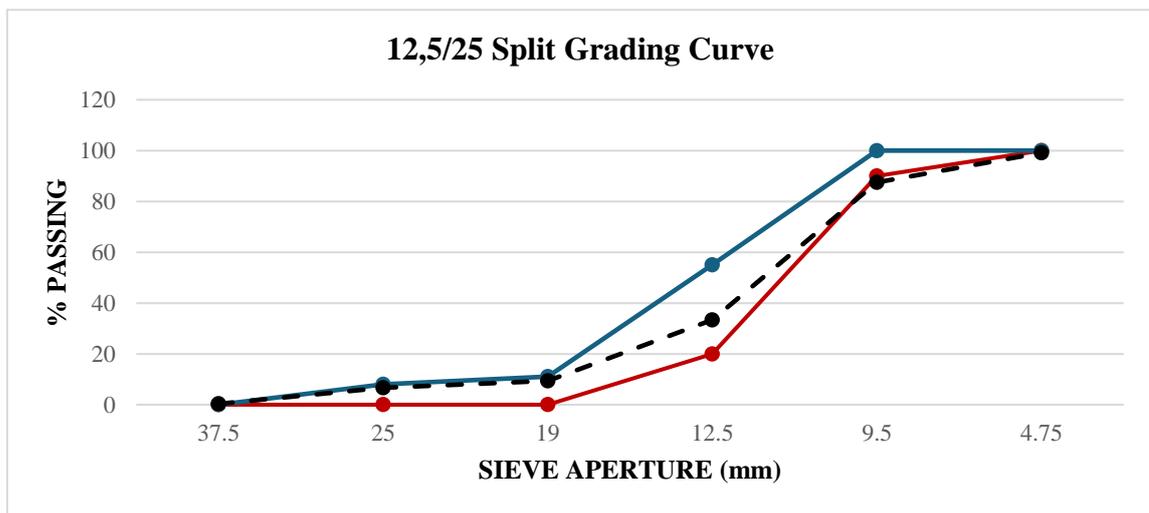
Source : Results of Laboratory Testing

The laboratory test results in Table 3 indicate that the 1” coarse aggregate fraction has excellent quality for use in structural concrete mixes. The colloid content of 0.30% reflects a high level of cleanliness, which enhances the bonding quality between particles in the concrete [13]. A fineness modulus of 7.60 indicates a predominance of larger particles, supporting compressive strength through optimal interlocking. The water absorption rate of 0.55% and moisture content of 0.10% suggest low porosity and ease in managing the concrete’s water content. The specific gravity of 2.63 also falls within the ideal range for producing dense, mechanically strong, and efficient concrete [14].

**Table 4.** Research Result of Sieve Analysis (2025)

Sieve aperture (mm)	Retained mass (gram)	% retained	% passing
37,5	13	0,87	99,13
25	188	12,53	87,47
19	1000	66,67	33,33
12,5	1360	90,67	9,33
9,5	1400	93,33	6,67
4,75	1495	99,67	0,33
PAN	1500	100	0

Source : Results of Laboratory Testing



Source : The Results at the Laboratory

**Figure 2.** Research Results on the Split Grading Curve (2025)

Figure 2 shows that the aggregate exhibits an appropriate (well-graded) particle size distribution, with a significant proportion of particles falling within the 12.5–25 mm range. Only 0.33% passes through the 4.75 mm sieve, indicating a very low fine fraction. The sharply declining grading curve at the smaller sieve sizes suggests an ideal aggregate structure for producing dense and homogeneous concrete [13].

## 2. Fine Aggregate

**Table 5.** Research Result of Fine Aggregate Testing (2025)

Item	Unit	Result
Colloid content	%	2,4
Fineness modulus		2,58
Water absorption	%	3,33
Moisture content	%	6,00
Specific gravity		2,58

Source : Results of Laboratory Testing

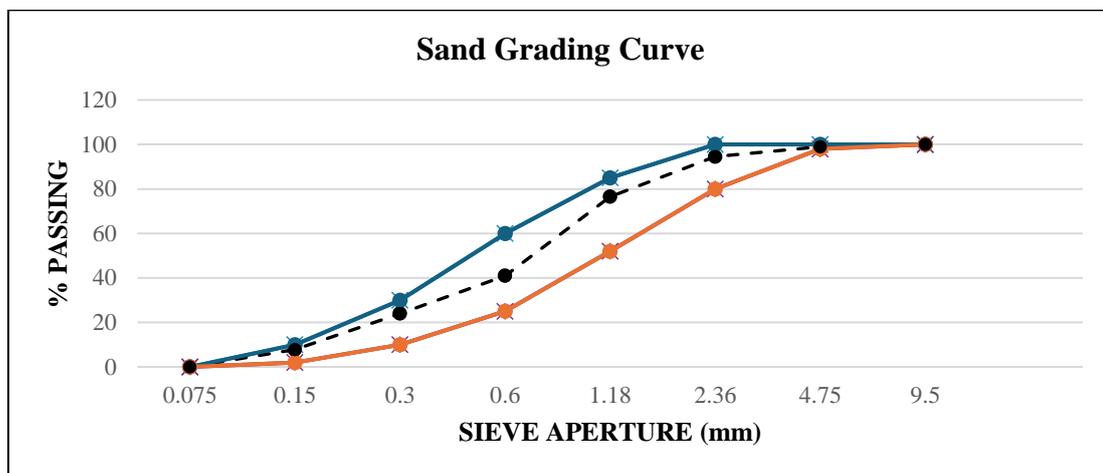
The fine aggregate test results in Table 5 show that the colloid content of 2.4% is still within acceptable limits, although relatively high, which may increase the water demand in the concrete mix. This level of fines could potentially reduce workability, thereby requiring

adjustments in the mix design [15]. The fineness modulus value of 2.58 indicates that the aggregate is classified as medium sand, which is ideal for supporting workability without compromising concrete strength. A water absorption rate of 3.33% is considered high, indicating significant aggregate porosity and an increased risk of excess water in the mix if not properly accounted for. In addition, with an aggregate moisture content of 6.00%, correction of the mixing water is essential to avoid imbalances in the concrete mixture [16]. The specific gravity of 2.58 reflects standard aggregate density, making it suitable for use in conventional concrete with good mechanical stability.

**Table 6.** Research Result of Sieve Analysis Fine Aggregate (2025)

Sieve aperture (mm)	Retained mass (gram)	% retained	% passing
9,5	0	0,00	100,00
4,75	11	1,10	98,90
2,36	55	5,50	94,50
1,18	240	24,00	76,50
0,6	590	59,00	41,00
0,3	760	76,00	24,00
0,15	922	92,20	7,80
PAN	1000	100,00	0,00

Source : Results of Laboratory Testing



Source : The Results at the Laboratory

**Figure 2.** Research Results on the Sand Grading Curve (2025)

Based on Figure 2, the aggregate exhibits a well-graded particle size distribution, with a dominance in the finer fractions (0.15 mm and 0.3 mm), which effectively fill the voids between coarse aggregates and enhance the concrete’s strength [16]. The grading curve shows a gradual decline, further confirming that the aggregate is well-graded.

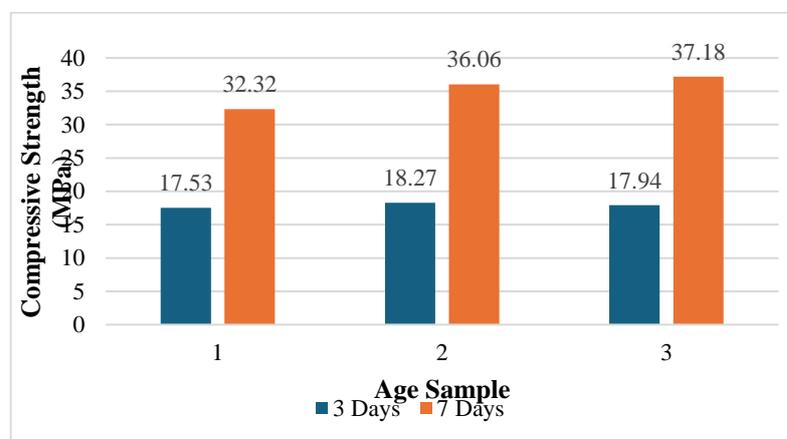
**Table 7.** Mix Design

Item	Unit	Fc'30 (7-day 100%)
Planned nominal slump	Cm	12 +-2
Water cement rasio	-	0,33
Cement OPC content	Kg/m <sup>3</sup>	530
Nominal water	lt/m <sup>3</sup>	175
Retarder : Celchem 08RS	lt/m <sup>3</sup>	1,86
Superplast : Celchem 75 RS	lt/m <sup>3</sup>	4,0
Coarse aggregate (3/4') 10-20mm	Kg/m <sup>3</sup>	480
Coarse aggregate (1') 20-30mm	Kg/m <sup>3</sup>	480
Fine aggregate	Kg/m <sup>3</sup>	710

Source : Results of Laboratory Testing

Based on Table 7, the concrete mix was designed to achieve a target compressive strength of Fc' 30 MPa within 7 days, with a water-cement (w/c) ratio of 0.33, indicating a high-performance mix with optimal density and strength. The cement content of 530 kg/m<sup>3</sup> is considered relatively high and aligns with the characteristics of high-strength concrete. The water content of 175 liters/m<sup>3</sup> is strictly controlled to maintain the mix's consistency and durability. Two types of chemical admixtures were used: 1.86 L/m<sup>3</sup> of Celchem 08 RS retarder and 4.0 L/m<sup>3</sup> of Celchem 75 RS superplasticizer, both serving to maintain workability (slump) over time without compromising the concrete's strength. The coarse aggregates were evenly divided between the 10–20 mm and 20–30 mm fractions, each at 480 kg/m<sup>3</sup>, providing a balanced gradation conducive to good concrete performance. Meanwhile, 710 kg/m<sup>3</sup> of fine aggregate contributed to void filling and enhanced the workability of the mix. Overall, the mix proportions indicate a well-balanced concrete design that optimizes strength, workability, and long-term durability.

## 4.2 Compressive Strength



Source : Results of Data Analysis

**Figure 3.** Compressive Strength Test Results of Early-Strength Concrete

Based on the test results shown in Figure 3, the early-strength concrete achieved an average compressive strength of 17.91 MPa at 3 days, which significantly increased to 35.19

MPa at 7 days. This increase demonstrates rapid strength gain at an early age, aligning with the primary objective of early-strength concrete design : to attain structural strength in a significantly shorter time than conventional concrete. According to the compressive strength growth curve, the concrete reached over 60% of the 7-day target strength within just 3 days.

This result is consistent with the concept of accelerated microstructure development, which is facilitated by the incorporation of chemical admixtures such as superplasticizer and silica fume. The use of superplasticizer (Celchem 75RS) has been proven to reduce water demand, enhance workability, and accelerate cement hydration, thereby expediting the formation of strength-giving gels in the concrete matrix [17], [18]. Meanwhile, silica fume, known for its high pozzolanic reactivity, improves pore structure and enhances the bonding strength between cement particles [19], [20].

From an implementation standpoint, the rapid achievement of compressive strength enables more efficient construction processes, such as earlier formwork removal, quicker reuse of molds, and the ability to proceed with reinforcement and subsequent structural phases sooner. This has a direct impact on cost efficiency and the acceleration of project timelines. Fast-setting concrete is particularly ideal for fast-track projects, such as road construction, temporary bridges, or precast structural elements [21], [22], [23].

From a managerial perspective, the successful application of early-strength concrete underscores the importance of material selection and mix design strategies informed by laboratory data. Project managers and construction planners must consider local material properties, work schedule requirements and site-specific climate conditions when designing an optimal job mix. According to a study by Ananyachandran, quality management plays a critical role in ensuring consistency in field applications, especially when utilizing rapid-strength concrete mixes [24].

In practice, these results demonstrate that a combination of high cement content (530 kg/m<sup>3</sup>) and a low water-cement ratio (0.33), along with the use of retarder and superplasticizer, can produce concrete capable of achieving high early strength. This finding aligns with research by C. Lee et al. and T. H. Wen et al., who reported that mix proportions and curing temperature are two critical factors influencing compressive strength development in early-strength concrete [25], [26].

## **5. Conclusion and Suggestion**

### **5.1 Conclusion**

This study concludes that the use of high early-strength concrete offers an effective solution for accelerating the construction process, particularly in infrastructure projects with limited execution time. The optimized concrete mix design achieved through appropriate aggregate selection and the incorporation of chemical admixtures proved capable of meeting early-age performance requirements. Test results showed that the early-strength concrete reached an average compressive strength of 17.91 MPa at 3 days which significantly increased to 35.19 MPa at 7 days. This increase indicates a rapid strength gain, with more than 60% of the 7-day target strength achieved within just 3 days. These findings align with the primary objective of early-strength concrete design, which is to achieve structural strength in a much shorter time than conventional concrete. The implementation of this strategy significantly contributes to improving construction efficiency, both in technical performance and project management aspects.

### **5.2 Suggestion**

To further enhance the outcomes of this research, future studies are recommended to explore the impact of varying admixture compositions and curing conditions on the long-term performance of high early-strength concrete. Incorporating real-time monitoring technologies

during the curing process on-site could also provide more precise data on strength development. Additionally, assessing the environmental impact and energy efficiency of using this type of concrete is essential to ensure that accelerated construction practices remain aligned with sustainable development principles.

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