Application of Statistical Quality Control in Monitoring Concrete Compressive Strength

William Bagita Samuel[1], Eswan[2], Wahyu Mahendra[2]
Department of Civil Engineering, Universitas 17 Agustus 1945, Samarinda
Email: [1] williambagitas30@gmail.com, [2]eswan@gmail.com, [3]mahendrawahyu@gmail.com

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Abstract

Concrete is a primary material in construction, directly influencing structural strength and stability. Therefore, quality control, particularly of compressive strength, is essential. This study evaluates the planned concrete strength of *f'c* 30 MPa used in the Presidential Parking Building Project at Indonesia's new capital, employing a Statistical Quality Control (SQC) approach. The main objective is to assess the stability of concrete quality and the effectiveness of various control chart methods in statistically monitoring the production process. A total of 32 compressive strength tests were conducted at 7 and 28 days, each involving three specimens. Five control chart methods were applied: $\bar{X}$, $\bar{R}$, $\bar{S}$, Moving Range (MR), and Moving Average (MA), based on SNI 1974:2011 standards. Results show that the $\bar{X}$ chart indicates the average compressive strength remains within control limits, suggesting process stability. $\bar{R}$ and $\bar{S}$ charts confirm controlled variation among samples, while MR charts reveal minor short-term fluctuations. MA charts successfully capture subtle trends without indicating significant process shifts. Overall, the concrete production process is statistically in-control. The combined use of these five control charts provides a comprehensive view of concrete quality; covering average, variation, and trend, and serves as a foundation for continuous quality improvement.

Keywords: *Concrete; Compressive strength; Control chart; Quality control; SQC*

1. Introduction

Concrete is the most widely used construction material in infrastructure development, including buildings, bridges, and highways. Compressive strength is the primary indicator of concrete quality, and testing at 7 and 28 days is standard practice for monitoring strength development and final performance [1], [2]. The quality of concrete is influenced by various factors such as mix proportions, material quality, mixing methods, casting procedures, and curing conditions [3]. Variations in these factors can lead to fluctuations in compressive strength results, necessitating a systematic and adaptive quality control system.

Statistical Quality Control (SQC) offers an effective approach to monitor and control product quality using statistical methods [4]. Control charts are the main tools in SQC, used to detect process stability and identify potential deviations. Commonly used charts include $\bar{X}$ (mean), $\bar{R}$ (range), $\bar{S}$ (standard deviation), Moving Range (MR), and Moving Average (MA) [5], [6]. These charts allow for comprehensive analysis of concrete quality stability.

This study evaluates the effectiveness of five control chart types in monitoring compressive strength data at 7 and 28 days. The goal is to contribute to the development of a more adaptive and accurate statistical quality control system in construction practices.

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2. Method

This research adopts a quantitative approach using SQC to analyze the stability of concrete quality based on compressive strength tests at 7 and 28 days. A total of 32 test events were conducted, each involving three specimens, in accordance with SNI 1974:2011 standards [7]. The data were grouped and analyzed using five control chart methods: $\bar{X}$, $\bar{R}$, and $\bar{S}$ for subgrouped data, and MR and MA for individual data [5], [8].

The $\bar{X}$ chart monitors the average compressive strength across subgroups, while the $\bar{R}$ and $\bar{S}$ charts assess variation among samples. MR charts detect short-term fluctuations in individual data, and MA charts reveal subtle trends over time [9]. Statistical software was used to process the data and generate control charts. Each chart was interpreted to determine whether the production process was statistically in-control, based on control limits and data patterns.

3. Results and Discussion

3.1. Statistical Summary of Compressive Strength

Concrete compressive strength was tested at 7 and 28 days across 32 test events, each involving 3 specimens. The statistical summary is shown below:

Table 1. Statistical Summary of Compressive Strength

Age (Days)	Minimum (MPa)	Maximum (MPa)	Mean (MPa)
7 Days	22.98	24.97	23.89
28 Days	26.93	43.42	34.58

3.2. Data Analysis

Data analysis in this study was carried out using quality control methods: $\bar{X}$, $\bar{R}$, $\bar{S}$, Moving Range, and Moving Average charts to evaluate the stability of 30 MPa concrete strength at 7 and 28 days. The analysis process was conducted systematically as follows:

a) $\bar{X}$ Bar Chart Analysis

The control limits for the $\bar{X}$ chart are calculated as:

Center Line (CL):

$$\bar{X} = \frac{1}{k}\sum_{i=1}^{k}\bar{X}_1 \tag{1}$$

Upper Control Limit (UCL):

$$UCL = \bar{X} + A_2 \cdot \bar{R} \tag{2}$$

Lower Control Limit (LCL):

$$LCL = \bar{X} - A_2 \cdot \bar{R} \tag{3}$$

Where:

$\bar{X}i$ = the mean of subgroup *i*, and *k* is the number of subgroups.

$\bar{R}$ = the average range

A_2 = a constant based on subgroup size (for n = 3, A_2=1.023)

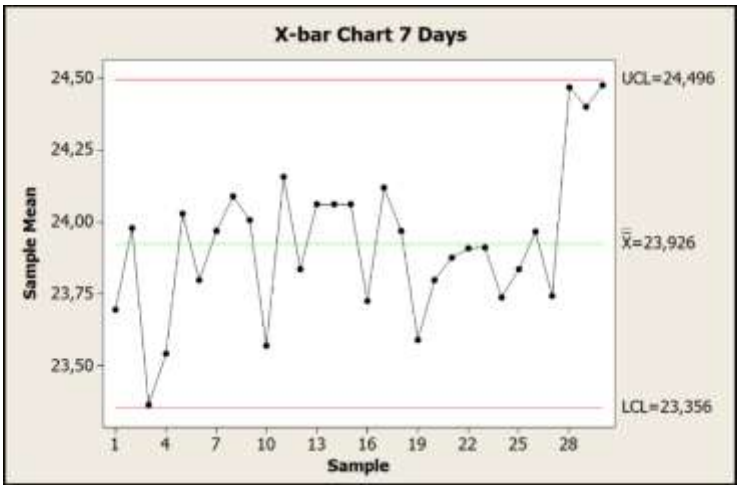

Figure 1. X-bar Chart 7 Days

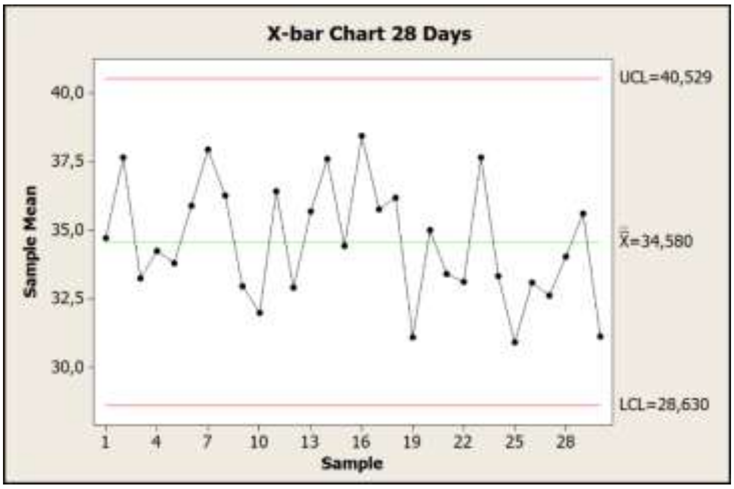

Figure 2. X-bar Chart 28 Day

The analysis using the $\bar{X}$ control chart shows that all compressive strength test data points fall within the upper and lower control limits, indicating a statistically stable process without significant deviations. The absence of out-of-control points confirms that observed variations are natural (common cause) rather than due to specific disruptions (special cause). Therefore, the concrete quality during the testing period is considered controlled and consistently aligned with the planned specifications.

b) $\bar{R}$ Bar Chart Analysis

The control limits for the $\bar{R}$ chart are calculated as:

Center Line (CL):

$$\bar{R} = \frac{1}{k}\sum_{i=1}^{k} \bar{R}_1 \tag{4}$$

Upper Control Limit (UCL):

$$UCL\ R = D_4\ x\ \bar{R} \tag{5}$$

Lower Control Limit (LCL):

$$LCL\ R = D_3\ x\ \bar{R} \tag{6}$$

Where

A_2, D_3, and D_4 = a constant based on subgroup size (e.g for n = 3, A_2 = 1.023, D_3 = 0, D_4 = 2.574)

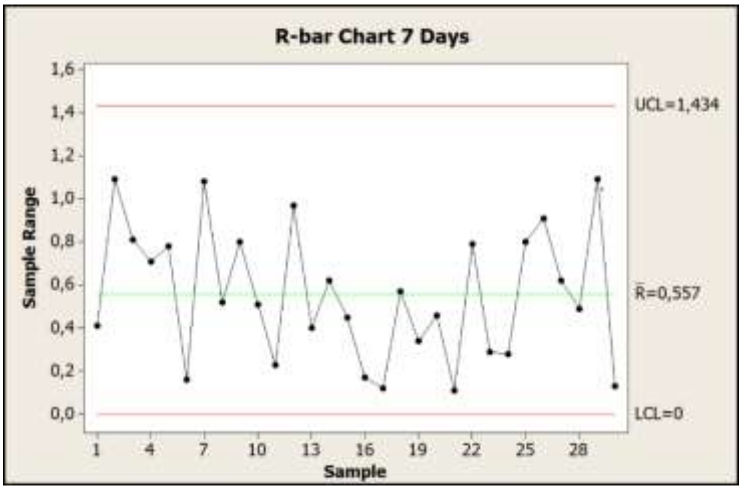

Figure 3. R-Bar Chart 7 Days

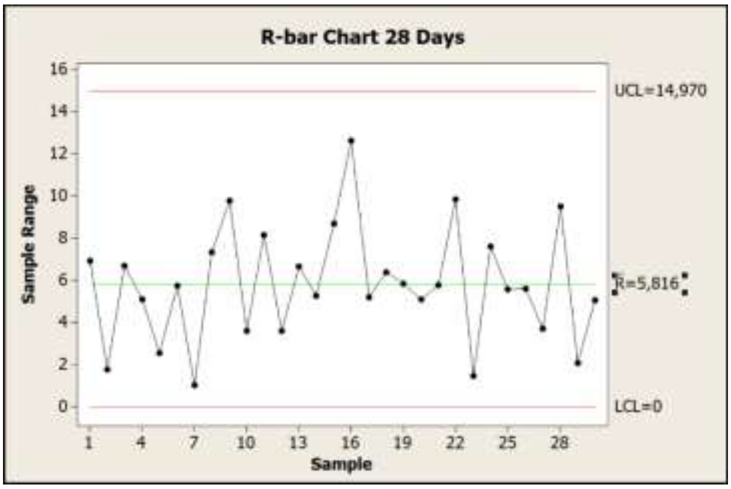

Figure 4. R-Bar Chart 28 Days

The $\bar{R}$ control chart analysis shows that all data points fall within the upper and lower control limits, indicating that sample-to-sample variation during testing is statistically stable and well-controlled. This confirms that the tested concrete quality is consistent and free from significant process deviations.

c) $\bar{S}$ Bar Chart Analysis

The control limits for the $\bar{R}$ chart are calculated as:

Center Line (CL):

$$\bar{S} = \frac{1}{k}\sum_{i=1}^{k} \bar{S}_1 \tag{7}$$

Upper Control Limit (UCL):

$$UCL\ S = B_4\ x\ \bar{S} \tag{8}$$

Lower Control Limit (LCL):

$$LCL\ S = B_3\ x\ \bar{S} \tag{9}$$

Where

B_3, and B_4 = a constant based on subgroup size (e.g for n = 3, B_3 = 0, B_4 = 2.568)

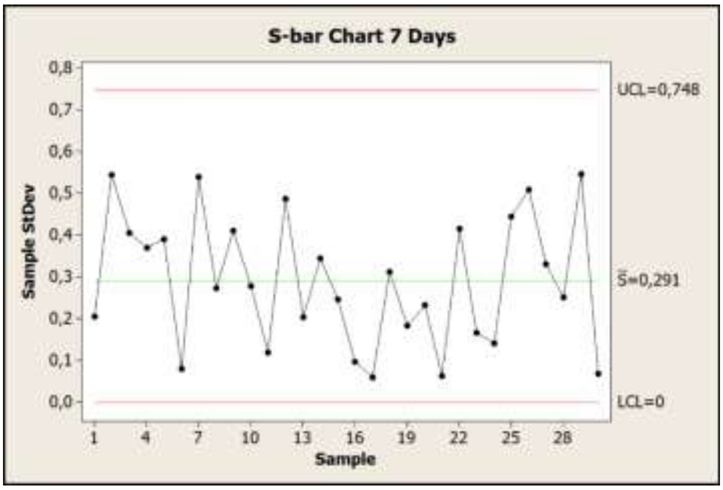

Figure 5. S-Bar Chart 7 Days

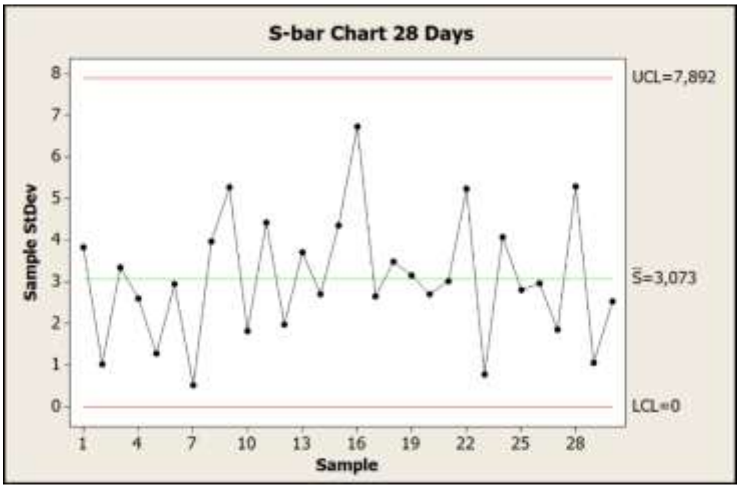

Figure 6. S-Bar Chart 28 Days

The $\bar{R}$ control chart analysis shows that all data points fall within the upper and lower control limits, indicating that sample-to-sample variation during testing is statistically stable and well-controlled. This confirms that the tested concrete quality is consistent and free from significant process deviations.

d) Moving Range (MR) Chart Analysis

Moving Range (MR) chart used for individual observations to detect short-term variation.
Average Moving Range:

$$\overline{MR} = \frac{\sum_{i=1}^{m} MR_i}{m-1} \tag{10}$$

Control Limits:

$$UCL\ MR = D_4\ x\ \overline{MR} \tag{11}$$

$$LCL\ MR = D_3\ x\ \overline{MR} \tag{12}$$

Where

D_3, and D_4 = a constant based on subgroup size (e.g for $n = 2$, $D_3 = 0$, $D_4 = 3.267$)

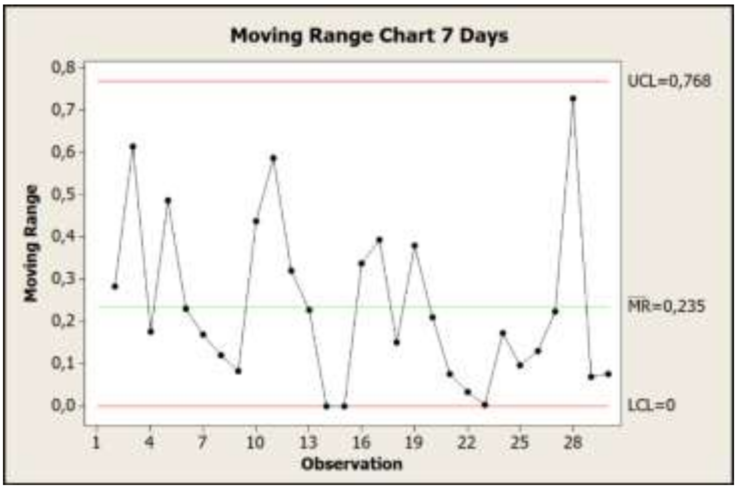

Figure 7. Moving Range (MR̄) Chart 7 Days

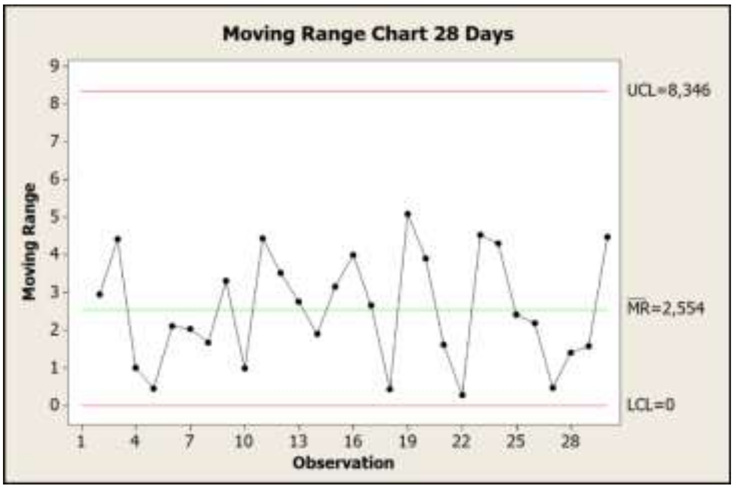

Figure 8. Moving Range (MR̄) Chart 28 Days

The Moving Range (MR) chart analysis shows that all data points fall within the established control limits, indicating that variations in compressive strength remain acceptable and do not signal significant process deviations. This confirms that the testing process is statistically stable, with observed fluctuations arising from natural variation rather than disruptive special causes.

e) Moving Average (MA) Chart Analysis

Moving Average (MA) chart used to detect long-term trends in individual data.

Center Line (CL):

$$CL\ \overline{MA} = \frac{\sum_{t=1}^{w} \bar{X}_t}{m} = \bar{\bar{X}} \tag{13}$$

Control Limits:

$$UCL\ MA = \bar{\bar{X}} + 3\ \frac{\sigma}{\sqrt{n\ t}} \tag{14}$$

$$LCL\ MA = \bar{\bar{X}} - 3\ \frac{\sigma}{\sqrt{n\ t}} \tag{15}$$

Where

D_3, and D_4 = a constant based on subgroup size (e.g for $n = 2$, $D_3 = 0$, $D_4 = 3.267$)

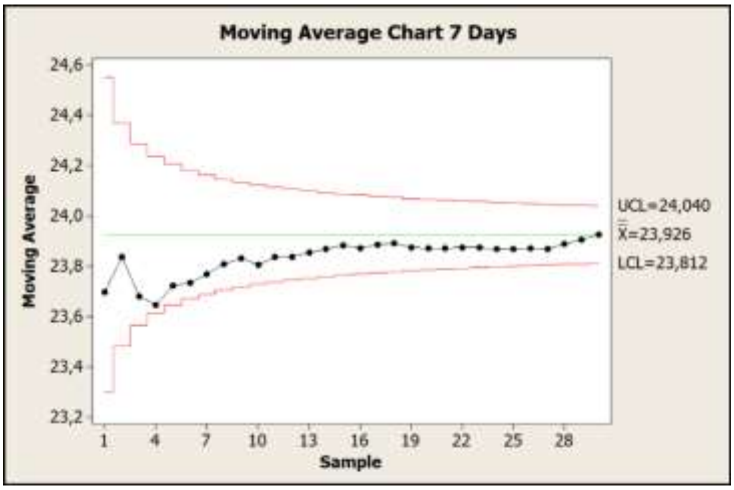

Figure 9. Moving Average (MA) Chart 7 Days

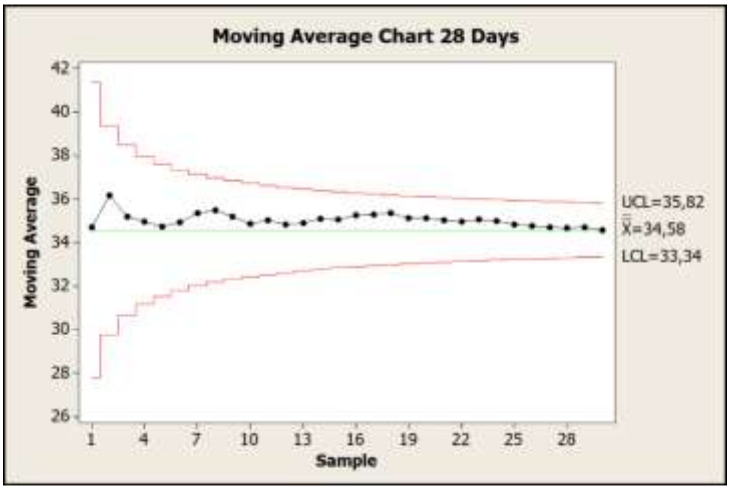

Figure 10. Moving Average (MA) Chart 28 Days

The Moving Average (MA) chart analysis shows that all data points remain within the upper and lower control limits, indicating statistically stable and controlled concrete quality throughout the testing period. The absence of out-of-control points confirms that observed variations are natural, and the concrete consistently meets the required standards at both 7 and 28 days.

4. Conclussion

The analysis of concrete compressive strength at 7 and 28 days using five control chart methods ($\bar{X}$, $\bar{R}$, $\bar{S}$, Moving Range, and Moving Average) shows that all test data fall within statistical control limits. This confirms that the concrete production process is stable and consistent, directly answering the research question regarding concrete quality at both testing ages.

Moreover, each control chart method contributes uniquely to monitoring concrete quality: $\bar{X}$ effectively reflects average strength stability, $\bar{R}$ and $\bar{S}$ assess sample variation, Moving Range detects sudden shifts between tests, and Moving Average captures long-term trends. The connection between the research question and findings is clear: using all five methods together provides a more comprehensive understanding of concrete quality variation and stability than relying on a single approach.

Finally, among the five control chart methods used, $\bar{S}$ and Moving Average charts are the most representative in illustrating concrete quality stability. The $\bar{S}$ chart effectively monitors homogeneity through standard deviation across sample groups, while the Moving Average chart clearly captures quality trends from 7 to 28 days. These two methods serve as the primary reference for evaluating concrete quality, with $\bar{X}$, $\bar{R}$, and Moving Range charts providing complementary analytical support.

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