Evaluation of 30 MPa Concrete Strength Using Inferential Statistics and Control Charts

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Abstract

This study aims to evaluate the quality and statistical control of 30 MPa concrete used in the construction of the Main Genset Building at Nusantara Capital City (IKN). The primary objective is to determine whether the concrete meets the design specifications and assess the statistical capability of its production process. A total of 69 concrete cylinder samples tested at 28 days were analyzed using two quantitative approaches: inferential statistics (normality test and one-sample t-test) and statistical quality control tools (control charts and process capability analysis).

Descriptive statistical analysis revealed that the average compressive strength at 28 days reached 33.464 MPa, exceeding the target value of 30 MPa. The normality test confirmed a normal distribution, validating the use of the T-test, which showed a statistically significant and positive deviation from the design strength. Control chart analysis indicated that the production process was stable and statistically controlled, fulfilling the prerequisites for process capability evaluation.

The process capability index (Cpk) was calculated at 1.101, suggesting that the production process is capable of meeting specification limits. However, the slightly lower Cpk compared to Cp (1.193) indicates a shift in the mean compressive strength toward the upper specification limit. The study concludes that the concrete quality meets design requirements with satisfactory process control, but recommends tighter control of material variability and adjustment of production settings to center the strength distribution, enhancing efficiency and reducing future quality risks.

Keywords: *Concrete compressive strength; Control chart; Inferential statistics; Nusantara Capital City (IKN); SPSS*

1. Introduction

Infrastructure development is widely recognized as a key indicator of national progress, serving not only as the foundation for economic growth but also as a driver of improved public welfare. In Indonesia, this commitment is reflected in strategic national initiatives aimed at equitable regional development, most notably the construction of the new capital city, Nusantara (IKN). As a megaproject with exceptional scale and complexity, IKN demands rigorous quality standards across all construction components. Among these, concrete plays a pivotal role as the primary structural material, where its performance directly influences the integrity, durability, and long-term sustainability of built assets [1], [2].

One of the critical facilities within IKN is the Main Genset Building, which supports the city’s energy infrastructure. The structural design of this building specifies a target compressive strength of 30 MPa for its concrete elements. Compressive strength testing is conducted at 7 days to monitor early strength development and at 28 days to verify characteristic strength, in accordance with national standards such as SNI 2493:2011 and SNI 1974:2011. However, achieving consistent strength across batches is inherently challenging due to variability in raw materials, mix proportions, environmental conditions, and field execution practices [3], [4]. These factors introduce fluctuations that, if left unmanaged, can lead to quality deviations and structural risks.

Traditional approaches to concrete quality evaluation often rely on simple comparisons between test results and minimum specification thresholds. While useful for basic compliance checks, such methods are insufficient for capturing the full statistical behavior of concrete performance or identifying hidden anomalies in the production process. To address this limitation, inferential statistics offer a more robust analytical framework. Techniques such as normality testing and one-sample t-tests enable generalization from sample data, hypothesis testing against design targets, and estimation of quality parameters with quantifiable confidence levels. These tools empower engineers and project managers to make informed decisions regarding batch acceptance and process adjustments [5], [6].

Beyond statistical inference, proactive quality control requires continuous monitoring of production stability. Control charts—specifically $\bar{X}$ and R charts—are widely used to distinguish between common-cause and special-cause variation in concrete strength data. When combined with process capability indices (Cp and Cpk), these tools provide a comprehensive view of whether the production process is not only stable but also capable of consistently meeting specification limits [7], [8]. Such integration of statistical process control (SPC) into concrete evaluation is particularly valuable in high-stakes projects like IKN, where reliability and repeatability are paramount.

The findings of this study are expected to offer both academic and practical contributions: enhancing the researcher’s analytical competence in statistical quality control, providing actionable insights for construction practitioners, and supporting data-driven quality assurance strategies in strategic infrastructure development. Ultimately, this research aims to strengthen the reliability and sustainability of concrete applications in IKN and similar national-scale projects [9], [10].

2. Method

In this study, the compressive strength performance of concrete used in the Main Genset Building at Ibu Kota Nusantara (IKN) was statistically evaluated to determine its conformity with the design specification of 30 MPa. A total of 138 cylindrical concrete samples, tested at both 7 and 28 days, were analyzed to assess the quality and consistency of the production process. The evaluation was conducted using a combination of descriptive statistics and inferential methods, including normality testing and one-sample T-tests, to verify the statistical significance of the strength results. In addition, the stability of the production process was examined through the application of control charts ($\bar{X}$ and R), while process capability was quantified using Cp and Cpk indices. All statistical computations and visualizations were performed using IBM SPSS Statistics software to ensure analytical precision and reproducibility.

3. Results and Discussion

This section presents the statistical evaluation of compressive strength data for concrete with a design target of f’c 30 MPa, the specimens in cylindrical (15 cm × 30 cm) at 7 and 28 days of age, following SNI 2493:2021. The analysis focuses on verifying strength compliance, assessing process stability, and determining production capability through inferential statistics and control chart methods.

Table 1. Compressive Strength Age 7 Days

Element Type	No. of Samples	Avg. Weight (kg)	Min–Max Weight (kg)	Avg. Strength (MPa)	Min–Max Strength (MPa)
Bore Pile	9	12.87	12.18 – 13.19	24.10	23.67 – 25.56
Sordier Pile	36	13.00	12.59 – 13.22	23.84	22.70 – 24.65
Caping Pile	3	13.01	12.78 – 13.14	23.98	23.95 – 24.04
Column	21	13.05	12.59 – 13.66	24.11	23.19 – 24.75

Table 2. Compressive Strength Age 28 Days

Element Type	No. of Samples	Avg. Weight (kg)	Min–Max Weight (kg)	Avg. Strength (MPa)	Min–Max Strength (MPa)
Bore Pile	9	12.70	12.41 – 12.80	32.99	28.07 – 37.82
Sordier Pile	42	12.91	12.16 – 13.18	33.41	26.59 – 41.46
Caping Pile	3	12.94	12.80 – 13.02	34.68	33.40 – 35.76
Column	15	13.01	12.74 – 13.29	32.27	27.99 – 38.60

3.1. Descriptive Statistical Analysis

Descriptive statistics were used to summarize the key characteristics of concrete samples tested at 7 and 28 days. A total of 69 samples per age group were analyzed for weight and compressive strength using SPSS.

Table 3. Descriptive Statistical Analysis Results of 7-Day Concrete Age

Concrete	N	Range	Minimum	Maximum	Sum	Mean	Std. Deviation
Concrete Weight	69	1.480	12.180	13.660	896.330	12.990	0.218
Compressive Strength	69	2.860	22.700	25.560	1653.400	23.962	0.498

At 7 days, the average concrete weight was 12.990 kg with a narrow range (12.180–13.660 kg) and low standard deviation (0.218 kg), indicating uniformity across samples. The average compressive strength reached 23.962 MPa, approximately 80% of the target f'c 30 MPa, consistent with expected early-age strength development.

Table 3. Descriptive Statistical Analysis Results of 28-Day Concrete Age

Concrete	N	Range	Minimum	Maximum	Sum	Mean	Std. Deviation
Concrete Weight	69	1.130	12.160	13.290	887.740	12.866	0.239
Compressive Strength	69	14.870	26.590	41.460	2308.990	33.464	3.432

At 28 days, the average weight was 12.866 kg with minimal variation (range: 12.160–13.290 kg; SD: 0.239 kg). Compressive strength averaged 33.464 MPa, exceeding the design target, with values ranging from 26.590 to 41.460 MPa and a standard deviation of 3.432 MPa. These results confirm that the concrete not only met but surpassed the required strength, reflecting effective production and curing processes.

3.2. Inferential Statistical Analysis

Inferential analysis was conducted to generalize sample findings to the population of concrete compressive strength. The procedure began with normality testing, which determined the appropriate statistical method. Parametric tests (T-test) were applied when normality assumptions were met; otherwise, non-parametric alternatives such as the Wilcoxon Signed-Rank Test were used. For variable associations involving non-normally distributed data, Spearman's rank correlation (ρ) was employed to ensure analytical validity.

3.2.2. Normality Testing

The analysis began with normality testing using Kolmogorov-Smirnov and Shapiro-Wilk methods for both concrete weight and compressive strength at 7 and 28 days.

Table 4. Normality Test Results for 7-Day Concrete Age

Variable	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Concrete Weight	0.193123	69	0.000	0.9205	69	0.0003
Compressive Strength	0.079516	69	0.200	0.9737	69	0.1542

Based on Table 4, normality tests using Kolmogorov–Smirnov and Shapiro–Wilk show that 7-day concrete weight data are not normally distributed (Sig. < 0.05), while compressive strength data are normally distributed (Sig. > 0.05). Therefore, parametric tests like the One-Sample T-Test can be used for strength analysis, while non-parametric methods such as Spearman's rank correlation are recommended for analyses involving concrete weight.

Table 5. Normality Test Results for 28-Day Concrete Age

Variable	**Kolmogorov-Smirnov**[a]			**Shapiro-Wilk**		
	Statistic	**df**	**Sig.**	**Statistic**	**df**	**Sig.**
Concrete Weight	0.113	69	0.0303	0.9290	69	0.0007
Compressive Strength	0.084	69	0.2000	0.9744	69	0.1689

Normality tests for 28-day data confirm compressive strength is normally distributed (Sig. > 0.05), while concrete weight is not (Sig. < 0.05). Thus, use parametric tests for strength and non-parametric methods (Spearman) for weight-related analysis.

3.2.3. T-Test Analysis

The One-Sample T-Test was used to evaluate whether the average compressive strength met or exceeded reference values.

Table 6. One-Sample T-Test Results for 7-Day Concrete Age

	t	**df**	**Sig. (2-tailed)**	**Mean Difference**	**95% Confidence Interval of the Difference**	
					Lower	**Upper**
Compressive Strength	0.084	69	0.2000	0.9744	69	0.1689

7-Day Test vs 21 MPa (70% of f'c 30 MPa) result shows the average strength was significantly higher than the reference, with a mean difference of +2.96 MPa (t = 49.419, p < 0.001). The 95% confidence interval (2.84–3.08 MPa) confirms strong early-age strength development.

Table 7. One-Sample T-Test Results for 28-Day Concrete Age

	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
Compressive Strength	8.384	68	0.0000	3.4636	2.6393	4.2880

28-Day Test vs 30 MPa result shows the average strength exceeded the design target by +3.46 MPa (t = 8.384, p < 0.001), with a confidence interval of 2.64–4.29 MPa. This indicates excellent concrete performance and a reliable safety margin.

3.2.4. Correlation Analysis

Spearman's rank correlation was used to assess the relationship between concrete weight and compressive strength at 7 and 28 days, due to non-normal data distribution.

Table 8. Correlation Results for 7-Day Concrete Age

Variable Pair	**Spearman's ρ**	**Sig. (2-tailed)**	**Interpretation**
Weight vs Compressive Strength	–0.0275	0.8222	Very weak negative, not significant

Correlation Coefficient (ρ = –0.0275) indicates a negligible negative relationship, suggesting that heavier specimens tend to have slightly lower strength, although the effect is minimal. Significance (p = 0.8222): Far above the standard threshold (α = 0.05), meaning the correlation is statistically insignificant. Thus, there are no meaningful relationship exists between concrete weight and compressive strength at 7 days. The observed trend is likely due to random sampling variation rather than a structural pattern.

Table 9. Correlation Results for 28-Day Concrete Age

Variable Pair	Spearman's ρ	Sig. (2-tailed)	Interpretation
Weight vs Compressive Strength	+0.1131	0.3548	Very weak positive, not significant

Correlation Coefficient (ρ = +0.1131) suggests a slight positive trend, where heavier specimens may exhibit marginally higher strength. Significance (p = 0.3548): Still above the α = 0.05 threshold, indicating the correlation is not statistically significant. Thus, at 28 days, the relationship remains weak and non-significant. The slight positive trend does not support a reliable predictive link between specimen mass and strength.

3.3. Control Chart for Concrete Compressive Strength

To ensure process stability and consistency, Statistical Process Control (SPC) was applied to compressive strength data using control charts. The analysis employed two variable charts: the X-bar chart to monitor central tendency across subgroups, and the R chart to assess internal dispersion. Together, they provide a comprehensive view of process accuracy and precision.

Control limits—Upper Control Limit (UCL), Center Line (CL), and Lower Control Limit (LCL)—were calculated and plotted using SPSS version 27.0.1.0. These charts serve as the basis for determining whether the testing process remains statistically in control.

3.3.1. X-bar Control Chart Analysis (7-Day Strength)

The X-bar control chart was used to assess the stability of average compressive strength across 23 concrete batches at 7 days.

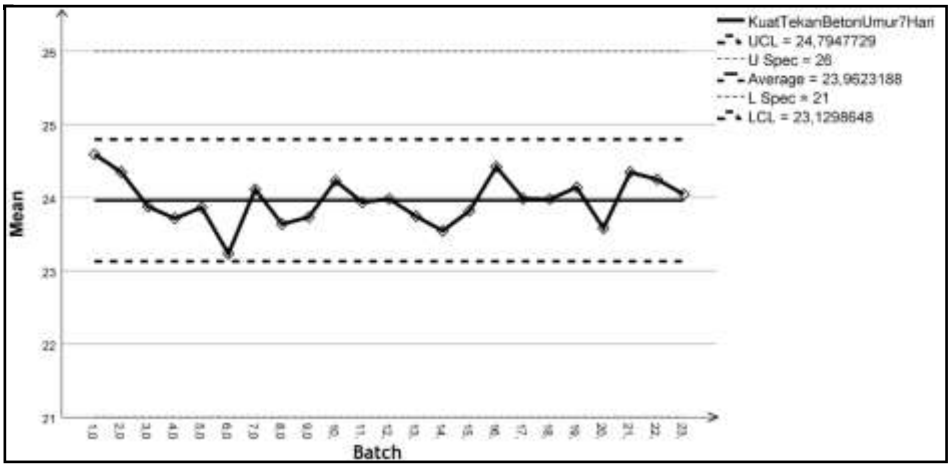

Figure 1. X-Bar Control Chart SPSS 7-Day Strength

The chart plots subgroup means (◊), with a center line (CL) at 23.96 MPa, and control limits calculated at UCL = 24.79 MPa and LCL = 23.13 MPa. Specification limits were visually set at 26 MPa (USL) and 21 MPa (LSL).

All data points fall within control limits and show no abnormal patterns, indicating the process is statistically stable. Variations in strength are consistent and predictable, suggesting reliable production quality at early age.

3.3.2. R-Bar Control Chart Analysis (7-Day Strength)

The R-chart was used to monitor the internal variability of compressive strength within each batch. It plots the range (max–min) of values per subgroup to assess process dispersion.

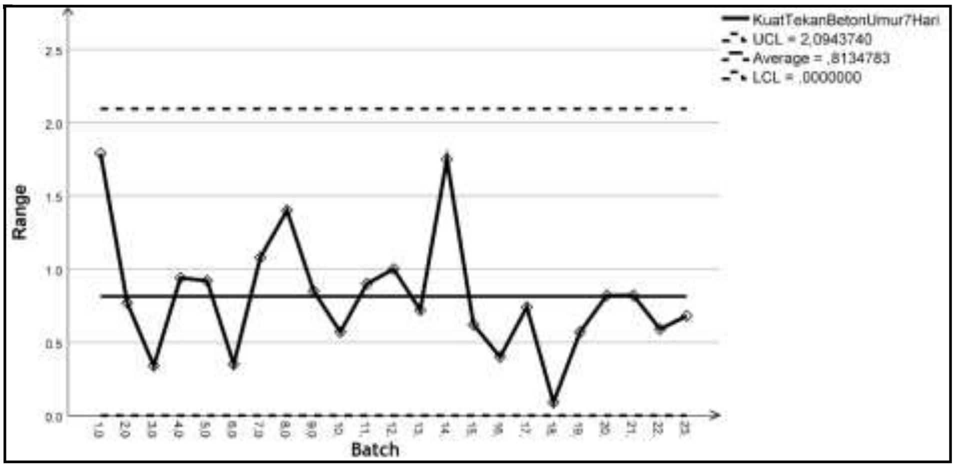

Figure 2. R-Bar Control Chart SPSS 7-Day Strength

The chart plots Center Line ($\bar{R}$): 0.813 MPa, Upper Control Limit (UCL): 2.094 MPa, Lower Control Limit (LCL): 0 MPa. All data points fall within control limits, indicating that variability across specimens in each batch is statistically stable. This confirms consistent mixing, casting, and testing procedures, with predictable strength dispersion across the 7-day samples.

3.3.3. Process Capability Analysis (7-Day Strength)

Following confirmation of process stability via X-bar and R charts, capability analysis was conducted to evaluate short-term potential and long-term performance of 7-day concrete strength.

Table 10. Capability Indices (Short-Term)

Index	Value	Interpretation
Cp	1.734	High potential to meet strength specs (21–26 MPa)
CpL	2.055	Excellent control below lower spec (21 MPa)
CpU	1.413	Slight tendency toward upper spec (26 MPa)
Cpk	1.413	Stable process with minor shift toward upper limit
K	0.185	Mean strength centered within spec range
CR	0.577	Variation well within tolerance

where:

Cp = Measures potential process capability assuming perfect centering; compares process spread to specification limits.
CpL = Capability of the process relative to the lower specification limit (LSL).
CpU = Capability of the process relative to the upper specification limit (USL).
Cpk = Actual process capability considering both spread and centering; lower of CpL and CpU.
K = Indicates how far the process mean deviates from the center of the specification range.
CR = Capability Ratio; compares process variation to specification width (CR < 1 is desirable).

Table 11. Performance Indices (Long-Term)

Index	Value	Interpretation
PP	1.674	Strong overall performance across all samples
PpL	1.983	Minimal risk of under-strength concrete
PpU	1.364	Some samples near upper spec—monitor for efficiency
PpK	1.364	Slight data shift, but still within control
PR	0.598	Acceptable variation relative to spec limits

where:
PP = Overall process performance using total variation across all data.
PpL = Performance relative to the lower specification limit.
PpU = Performance relative to the upper specification limit.
PpK = Actual performance index considering centering and total variation.
PR = Performance Ratio; compares actual process spread to specification limits (PR < 1 indicates acceptable variation).

The 7-day concrete production process is statistically stable and capable (Cpk > 1.33), with nearly all samples meeting strength requirements. While performance is strong, occasional values near the upper limit suggest the need for mix optimization to avoid material excess. These indices confirm high consistency, structural reliability, and effective quality control.

3.3.4. X-bar Control Chart Analysis (28-Day Strength)

The X-bar chart for 28-day compressive strength—critical for verifying compliance with the design target of f’c 30 MPa—was constructed using 23 batch averages.

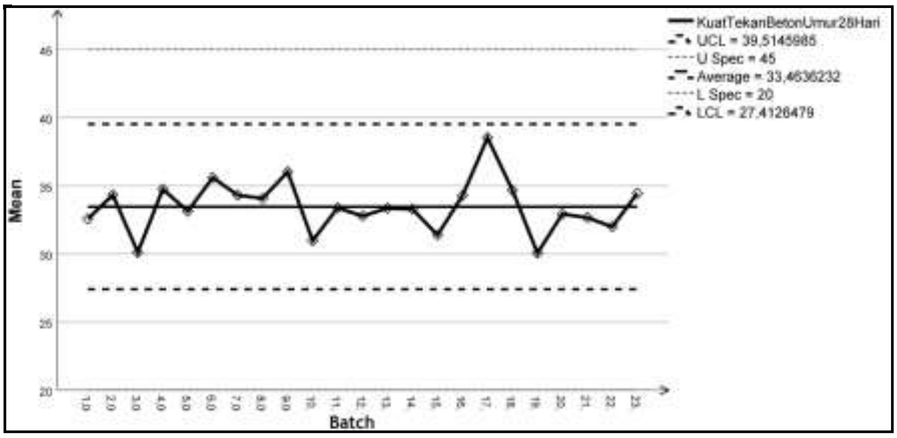

Figure 3. X-Bar Control Chart SPSS 28-Day Strength

The chart plots Center Line (CL): 33.46 MPa, Upper Control Limit (UCL): 39.51 MPa, Lower Control Limit (LCL): 27.41 MPa, Specification Limits: 20 MPa (LSL) to 45 MPa (USL). All batch averages fall within control limits, with no signs of outliers or non-random patterns. This confirms the process is statistically stable. Moreover, all values lie well within specification limits, indicating the process is not only stable but also capable of consistently producing concrete that meets or exceeds the required 28-day strength.

3.3.5. R-Bar Control Chart Analysis (28-Day Strength)

The R-chart was used to assess internal variability of compressive strength across 23 batches at 28 days.

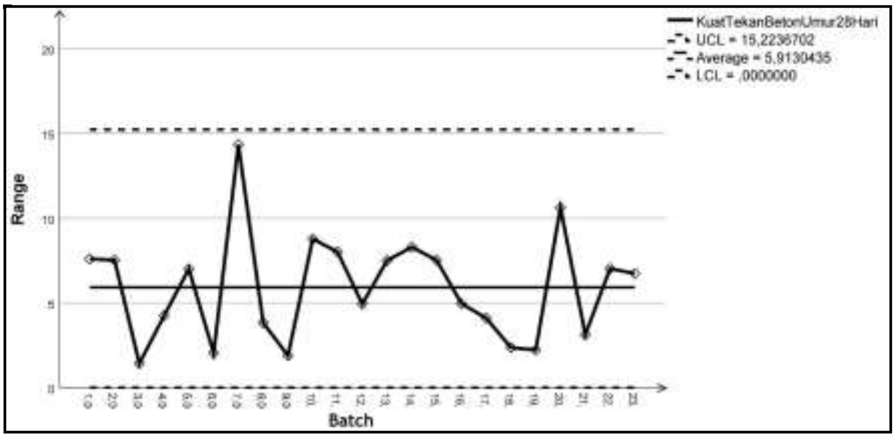

Figure 4. R-Bar Control Chart SPSS 28-Day Strength

Control limits were set as follows: Center Line ($\bar{R}$): 5.91 MPa, Upper Control Limit (UCL): 15.22 MPa, Lower Control Limit (LCL): 0 MPa. All data points fall within control limits, confirming stable and predictable variability within each batch. Combined with the X-bar chart, this indicates the 28-day concrete production process is statistically stable and capable of consistently meeting final strength specifications.

3.3.6. Process Capability Analysis (28-Day Strength)

Following confirmation of process stability via control charts, capability indices were evaluated to assess how well the 28-day concrete strength meets specification limits (20–45 MPa).

Table 12. Capability Indices (Short-Term)

Index	Value	Interpretation
Cp	1.193	moderate potential to meet specs; process is capable but close to limits.
CpL	1.285	Strong control below LSL, but some values approach USL.
CpU	1.101	
Cpk	1.101	Actual capability slightly lower than Cp, suggesting minor shift in mean.
K	0.077	Mean strength is well-centered.
CR	0.838	Variation remains within acceptable range.

Table 13. Performance Indices (Long-Term)

Index	Value	Interpretation
PP	1.214	Long-term performance is solid, with low risk of under-strength concrete and minor tendency toward upper spec.
PpL	1.308	
PpU	1.121	
PpK	1.121	
PR	0.824	Confirms actual variation is within safe limits.

The 28-day concrete production process is stable and capable, with most samples meeting strength targets. However, the slight shift toward the upper spec limit suggests the need for tighter quality control to maintain efficiency and avoid excessive strength beyond design requirements.

4. Conclussion

The evaluation of concrete compressive strength confirms that quality targets were successfully met. At 7 days, the average strength reached 23.962 MPa, indicating strong early development. By 28 days, the average increased to 33.464 MPa, significantly exceeding the design target of f’c 30 MPa. Inferential analysis (One-Sample T-Test) validated that this positive deviation is statistically significant.

Correlation testing using Spearman’s rho revealed no meaningful relationship between concrete weight (density) and compressive strength at 28 days ($\rho = 0.113$; Sig. = 0.355), suggesting that density was not a determining factor in strength variation for this project.

Process stability was confirmed through X-bar and R control charts, with all data points remaining within control limits at both 7 and 28 days. This indicates that the production process was statistically in control, free from special cause variation.

Process capability analysis at 28 days yielded a Cpk of 1.101, demonstrating that the process is capable of consistently meeting strength specifications. However, the lower Cpk compared to Cp (1.193) suggests a slight shift in the mean strength toward the upper specification limit. While still within acceptable bounds, this trend highlights the need for ongoing quality control to maintain efficiency and prevent excessive strength beyond design requirements.

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