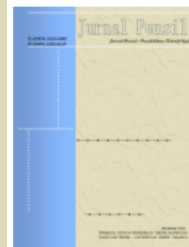


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INFLUENCE OF IN-SITU CONCRETE AND REINFORCING STEEL PROPERTIES ON THE SERVICEABILITY PERFORMANCE OF REINFORCED CONCRETE FRAMES

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Abstract

This study evaluates the influence of differences between planned and in-situ material properties on the structural performance of a reinforced concrete frame building. The research focuses on field-tested concrete and reinforcing steel properties and their effects on structural capacity and serviceability. A case study was conducted on the Ministry of Finance Apartment Building in Denpasar through material testing, structural assessment, and numerical modeling using SAP2000. The test results showed that the in-situ concrete compressive strength ranged from 24.5 MPa to 25.2 MPa, slightly lower than the design value, while the reinforcing steel exhibited a higher yield strength than specified in the design. The increase in steel strength improved beam flexural capacity by approximately 3.3%, whereas the reduction in concrete strength decreased column axial capacity by around 4.6%. Despite these variations, the Strong Column–Weak Beam (SCWB) ratio remained within the acceptable range of 1.48–2.00. Structural analysis also indicated that interstory drift and P–Delta effects satisfied the requirements of SNI 1726:2019, confirming adequate lateral stiffness and structural stability. The findings indicate that variations in actual material properties do not significantly reduce overall structural performance, although they may influence the structural safety margin and capacity balance. This study emphasizes the importance of field material verification to ensure the reliability of earthquake-resistant reinforced concrete structures.

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Keywords: In-Situ Concrete, Reinforcing Steel, Structural Serviceability, SCWB, Material Quality Evaluation

Introduction

Reinforced concrete is the main material used in building construction in Indonesia because it is economical and has good compressive strength (Sunil et al., 2026). Concrete has high compressive strength, while its main weakness, which is its low tensile strength, is overcome by the use of steel reinforcement (Roschedy et al., 2019). The combination of concrete and steel reinforcement can effectively withstand tensile and compressive loads on structural elements (Sagita et al., 2020). However, in practice, the quality of concrete and reinforcing steel installed in the field often differs from the planned quality (Mujtaba et al., 2018). These differences can occur due to factors such as variations in mix proportions, aggregate quality, casting methods, maintenance, and suboptimal quality control (Hanan et al., 2023). Theoretically, a reduction in the actual concrete quality can decrease the compressive capacity of columns, which are key elements in maintaining the structural stability of a building. This reduction in capacity directly affects the column's ability to resist a combination of axial load and moment, particularly under seismic loading conditions (Baktheer et al., 2026). In this study, the effect of actual concrete quality is evaluated through structural performance parameters, such as deformation, internal force distribution, and the capacity ratio of structural elements. Thus, changes in concrete quality are examined not only from a material perspective but also in terms of their impact on the overall behavior of reinforced concrete structures (Mirmoghtadaei et al., 2026). On the other hand, improving the quality of reinforcing steel can increase the flexural capacity of both beams and columns (Val et al., 2025). However, an imbalance in capacity gains between elements has the potential to affect the Strong Column Weak Beam (SCWB) mechanism, which is a key principle in seismic design (Yin et al., 2023). Therefore, the evaluation of structural parameters in this study was conducted to identify the extent to which variations in actual material quality affect service performance and the balance of capacity between structural elements (Yang et al., 2025).

Columns with lower than planned capacity can increase the risk of early collapse, especially in earthquake conditions where columns must withstand a combination of axial loads and moments (Ranee, 2016). Conversely, higher-grade reinforcing steel can increase the flexural capacity of structural members, particularly in beams and columns (Ribeiro et al., 2026). However, this increase in capacity does not always benefit the overall structural behavior (Kufner et al., 2025). Excessively large capacity differences between structural members can affect the design capacity balance and alter the intended failure mechanism (Monaco et al., 2023). In earthquake-resistant structures, the Strong Column Weak Beam (SCWB) principle must be maintained so that plastic hinges form first in the beams, allowing structural failure to proceed in a more ductile and controlled manner (Felber et al., 2026). If an increase in steel quality causes the beam's capacity to exceed the column's capacity at the connection zone, the potential for column failure increases and may reduce the overall safety level of the structure (Bin Azuwa & Bin Mat Yahaya, 2024). Therefore, the influence of variations in reinforcing steel quality in this study is examined not only in terms of increased element strength but also in terms of changes in the balance of capacity and structural behavior in meeting serviceability and seismic design performance criteria (Rangan, 2023). This condition is advantageous on one hand, but on the other hand, it has the potential to disrupt the balance between the capacity of beams and columns (Prima et al., 2019). In earthquake-resistant structural design, this balance is very important because it must meet the Strong Column Weak Beam (SCWB) principle, namely that the capacity of the column must be greater than the capacity of the beam at the joint, so that the plastic hinge is formed first in the beam, not in the column (Shahnazi et al., 2026). Previous research has generally focused on structural design and material quality based on design specifications, such as the effect of reinforcing steel quality on the capacity of structural elements and the application of the Strong Column Weak Beam (SCWB) principle in earthquake-resistant buildings (Abadi et al., 2022). However, most of these studies still assume that the quality of materials on-site matches the specified quality, and thus have not extensively addressed the discrepancy between the actual quality of the materials used and the

resulting structural capacity (Aljaafreh et al., 2023). In fact, variations in the quality of reinforcing steel on-site can affect the balance of beam and column capacity and impact the serviceability and safety of the building structure (El-Naqeeb et al., 2025). Therefore, this study focuses on evaluating the effect of variations in the actual quality of reinforcing steel on the behavior and capacity of reinforced concrete structures, particularly in relation to compliance with the SCWB concept in earthquake-resistant buildings (Alihudien et al., 2025). Several recent studies have also shown that discrepancies in material quality on-site remain a key factor affecting the performance of reinforced concrete structures, particularly in buildings located in earthquake-prone areas (Formisano et al., 2025). Therefore, evaluating the actual quality of materials is essential to ensure the safety and reliability of structures under on-site construction conditions (Suhana, 2016). In fact, these differences can have a significant impact on the serviceability and safety of buildings (Gumilar P et al., 2022). Research by (Bobek et al., 2024) emphasizes the importance of material quality accuracy on the performance of earthquake-resistant structures, while a local study (El-Naqeeb et al., 2025) shows that concrete quality variations of 5-10% can affect the capacity of compression elements by up to 7%. This highlights the need for a specific evaluation of the quality of materials used in construction (Lailaningrum et al., 2014).

Based on this, this study takes a case study of the Ministry of Finance ASN Apartment Building in Denpasar, which uses a reinforced concrete frame structure (Alfaries et al., 2026). The focus of the study is on evaluating the quality of installed concrete and steel reinforcement (Solin, 2022), analyzing its effect on the capacity of columns and beams, and assessing the fulfillment of the SCWB principle (Ostapska et al., 2025). This evaluation was carried out by comparing the planned quality and actual quality from the test results, as well as assessing their impact on the serviceability of the structure in accordance with applicable standards, namely SNI 2847:2019 concerning structural concrete requirements and SNI 1726:2019 concerning earthquake resistance planning (Azizi et al., 2020). Thus, this study is expected to provide practical contributions in understanding the impact of variations in concrete and steel reinforcement quality on the reliability of multi-story buildings in Indonesia (Rokhman et al., 2023). In addition, the results of this study can be used as a reference for planners in evaluating material quality in the field, so that the SCWB principle is maintained and the structure performs safely and reliably under seismic loads (Alfaries et al., 2026).

Research Methods

This research is a comparative analysis based on field data and laboratory testing of the quality of reinforcing steel in existing structures (et al., 2021). The analysis was conducted by comparing the quality of installed materials from testing with the quality of design materials, then evaluating their impact on the capacity of structural elements and compliance with the Strong Column Weak Beam (SCWB) concept (Septiarsilia et al., 2024). The research subject is the Ministry of Finance's civil service building in Denpasar, which utilizes a multi-story reinforced concrete structural system. The research focuses on beams and columns, which play a critical role in resisting seismic loads. Primary data was obtained through laboratory testing of reinforcing steel and field observations, while secondary data was derived from design drawings, technical specifications, and building structural documents (Deeba & Ammasi, 2024). Test results were then analyzed to determine the differences between actual and design quality and their impact on structural behavior and capacity. c Ministry of Finance Apartment Building in Denpasar, a multi-story building with a reinforced concrete frame system. The main column and beam elements analyzed were selected based on the results of a preliminary evaluation of the building's structural system, particularly those elements that bear the heaviest load combinations and play a role in the seismic resistance mechanism (Amalia & Sabariman, 2021). The selection focused on structural elements on specific floors deemed critical based on their dimensions, load distribution, and their role in fulfilling the Strong Column Weak Beam (SCWB) concept (Dwi Wahyuni et al., 2021). The information utilized in this research comprised both original and secondary sources. The primary

data in this study were obtained through direct material quality testing in the field and in the laboratory. Concrete testing was conducted using core samples taken from columns and beams to determine the actual compressive strength of the concrete in accordance with SNI 1974:2011. The number of sampling points was adjusted according to the structural elements examined on several floors of the building that were considered critical in terms of seismic loads. In addition, tensile testing of reinforcing steel was conducted to obtain the yield stress (f_y), tensile strength, and other mechanical characteristics in accordance with SNI 07-2052-2017. Sampling was performed on existing buildings, taking into account the structural condition and age of the concrete at the time of testing (Basoka, 2020). The actual concrete quality was determined through compressive strength tests on cylindrical test specimens taken from column and beam structural elements in accordance with SNI 1974:2011 (BSN, 2011), then the average value and characteristic compressive strength were calculated. In addition, Reinforcing steel testing was conducted on several samples of primary reinforcement taken from beam and column elements at locations within the structure deemed representative of the building's overall condition. The diameters of the tested reinforcement included the primary reinforcement most commonly used in structural elements, namely the longitudinal reinforcement of beams and columns, as per the design data. Sampling was performed at several points and floors of the building that play a critical role in the seismic load-bearing system and bear relatively large structural loads. The samples used in this study were selected to represent the actual material conditions of the primary structural elements, so that the test results can serve as the basis for evaluating the conformity of the reinforcing steel's quality with the design specifications. (BSN, 2017).

Meanwhile, secondary data was obtained from design documents and planning drawings that included structural element dimensions (columns and beams), planned concrete and steel quality, and reinforcement details. This secondary data was used as a comparison to determine the extent of the difference between the planned material quality and the installed conditions. In addition to material data, this study also used structural modeling with SAP2000 software. The structure was modeled according to design documents such as dimensions, material quality, and element details. This modeling aimed to simulate the overall behavior of the structure, particularly in calculating interstory drift due to planned earthquake loads. The modeling results are shown in Figure 1, which shows a three-dimensional view of the structure along with the distribution of lateral displacement on each floor (Formisano et al., 2025). This drift analysis is then compared with the limit specified in SNI 1726:2019, which is 2% of the floor height. Thus, the analysis not only assesses the quality of concrete and reinforcing steel in the materials, but also evaluates the overall performance of the structure to ensure the serviceability of the building (Miceli et al., 2025).

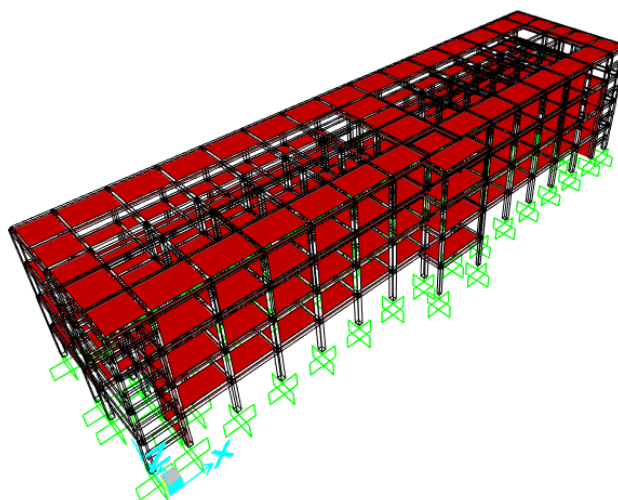


Figure 1. 3D Structural Modeling

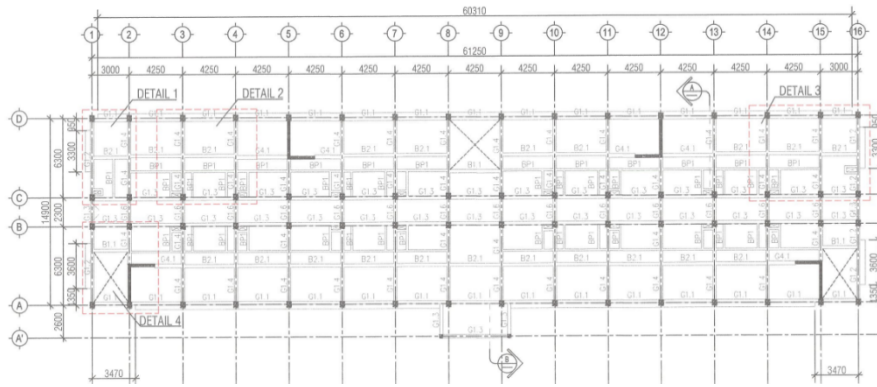


Figure 2. Floor Plan of the Building

In structural loading analysis, the working loads were determined based on the provisions of SNI 1727:2020 and SNI 1726:2019. The calculated loads consisted of dead load, live load, and earthquake load. The dead load applied to the slab included the self-weight of reinforced concrete slabs, ceiling and hanger loads, floor finishing, and mortar layers in accordance with SNI 1727:2020. Meanwhile, the live load was assigned based on the functional use of the building area. The earthquake load was calculated using the response spectrum method according to SNI 1726:2019 by considering the seismic parameters for the Denpasar region. These loading parameters were subsequently applied in the structural model to evaluate the behavior, stiffness, and overall structural performance of the building.

Research Results and Discussion

Drift Analysis

Table 1 presents the results of the interstory drift analysis for each floor level of the structure. The displacement values represent the lateral deformation caused by earthquake loading. The results show that the maximum inelastic drift occurs on the second floor with a value of 34.38 mm, while the smallest drift occurs on the first floor with 23.10 mm. These values are significantly smaller than the allowable drift limit of 51.54 mm, which was determined based on SNI 1726:2019 using the allowable interstory drift limit of 1.5% of the story height. Which corresponds to 2% of the floor height according to SNI 1726:2019. This indicates that the lateral deformation of the structure remains within the serviceability limits required by the code.

The distribution of interstory drift along the building height is illustrated in Figure 2. The graph shows that the largest deformation occurs in the middle floors, particularly on the second floor, while the displacement on the ground floor and upper floors is relatively smaller. This behavior is typical in multi-story buildings subjected to lateral loads, where the maximum deformation tends to occur at intermediate levels due to the distribution of stiffness and mass along the structure.

Table 1. Interstory Drift

Floor level	Displacement	Elastic Drift	Height	Inelastis Drift	Drift Limit	Check
	δe_y (mm)	δe_y mm	h mm	Δy mm	mm	
4	18.000	2.500	3350	13.750	51.54	OK
3	15.500	5.050	3350	27.775	51.54	OK
2	10.450	6.250	3350	34.375	51.54	OK
1	4.200	4.200	3350	23.100	51.54	OK

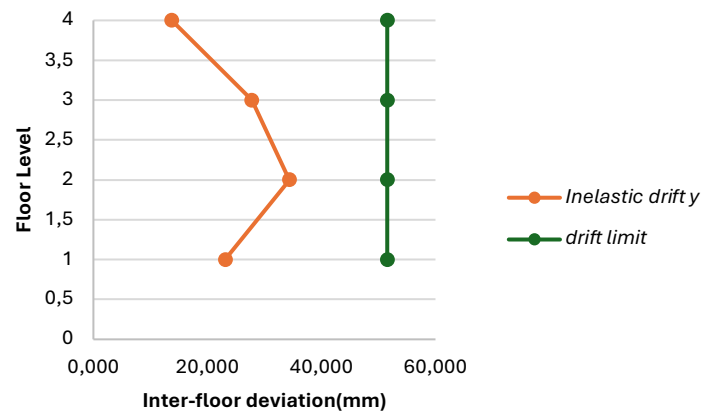


Figure 3. Interstory Drift Distribution

Table 2 shows the results of the P-Delta stability evaluation, which represents the additional structural deformation caused by axial forces acting on laterally displaced columns. The parameter used to evaluate this effect is the stability coefficient (θ). The calculation results show that the θ values for all floors range between 0.000 and 0.002, indicating that the additional secondary moments caused by axial loads and lateral displacement are relatively insignificant compared to the primary structural response. Therefore, the P-Delta effect does not critically affect the stability of the structure, which are significantly lower than the allowable limit of 0.1. This indicates that the influence of the P-Delta effect on the structural behavior is very small and does not significantly affect the stability of the building.

The relationship between interstory drift and the stability coefficient is presented in Figure 3. The graph shows that the θ values remain relatively constant at each floor level and are positioned far below the stability limit line. This confirms that the building structure has sufficient lateral stiffness to resist additional deformation caused by axial loads.

Table 2. Stability (P-Delta)

Floor Level	Elastic Drift Δy mm	Story force V_y kN	Height h mm	Stability coefficient θ_y	P-delta influence limit	Structural stability limit θ_{max}	Check
4	2.500	1458.84	3350	0.000	0.1	0.091	OK
3	5.050	4156.58	3350	0.000	0.1	0.091	OK
2	6.250	5750.32	3350	0.002	0.1	0.091	OK
1	4.200	7315.34	3350	0.002	0.1	0.091	OK

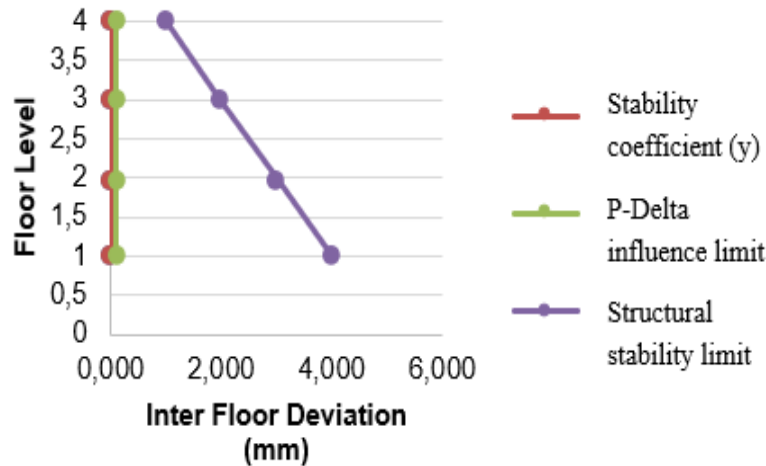


Figure 4. P-delta stability

Table 3 displays the findings from the tests conducted on the compressive strength of concrete. conducted on column and beam elements from the first to the fourth floor. The test results show that the average compressive strength values are relatively consistent across all floors. The average strength for column elements is approximately 25.0 MPa, while the beam elements have similar values ranging between 24.8 MPa and 25.1 MPa. The small variation between floors indicates that the concrete quality used in the structure is relatively uniform.

The consistency of concrete quality is important because columns function as the main structural elements that carry vertical loads and contribute significantly to the overall stability of the building. Large variations in concrete strength could reduce the axial capacity of the columns and potentially affect the structural safety. However, based on the test results presented in Table 3, the concrete quality can be considered stable and adequately controlled during construction.

Table 3. Compressive strength of concrete in columns and beams

No.	Compressive strength test (MPa)							
	Floor 1		Floor 2		Floor 3		Floor 4	
	Columns	Beams	Columns	Beams	Columns	Beams	Columns	Beams
1	22	22	24	22	24	24	22	24
2	26	24	24	24	24	24	22	20
3	22	24	26	24	28	26	28	24
4	24	26	26	26	28	28	28	24
5	26	24	28	26	28	29	28	24
6	24	24	22	28	26	26	26	26
7	26	28	30	30	26	26	22	26
8	26	26	24	24	22	28	28	24
9	26	22	24	22	24	22	24	28
10	28	30	22	24	22	22	22	28
Total	250	250	250	250	252	251	250	248
Average	25.0	25.0	25.0	25.0	25.2	25.1	25.0	24.8

Table 4 compares the planned concrete compressive strength ($f_c = 24.9$ MPa) with the actual concrete strength obtained from field test results. The installed concrete compressive strength ranges from 24.3 MPa to 25.0 MPa, with standard deviation values between 0.27 and 0.33.

The percentage deviation between the planned and installed concrete strength is relatively small, ranging from 1.0% to 1.3%.

These values are well below the allowable tolerance limit of 5% specified in SNI 2847:2019, indicating that the variation in concrete compressive strength remains relatively small. Statistical evaluation also showed low variability among the test results, confirming consistent concrete quality during construction. Below the allowable tolerance limit of 5% specified in SNI 2847:2019, which indicates that the installed concrete quality still meets the design requirements. Therefore, the variation in concrete strength observed in the field does not significantly affect the structural capacity. The comparison between the compressive strength of columns and beams is illustrated in Figure 5. The graph shows that the strength values for both structural elements follow a similar pattern across all floors, indicating consistent material quality throughout the building structure.

Table 4. Comparison of planned and installed concrete compressive strength

Elemen & Floor	Average compressive strength (MPa)	Installed characteristics (MPa)	Planned characteristics (MPa)	Std. Deviation	Deviation (%)	Description
Column Lv. 1	25.0	24.6	24.9	0.27	1.07	OK < 5%
Column Lv. 2	25.0	24.5	24.9	0.31	1.23	OK < 5%
Column Lv. 3	25.2	24.7	24.9	0.30	1.19	OK < 5%
Column Lv. 4	25.0	24.5	24.9	0.33	1.30	OK < 5%
Beam Lv. 1	25.0	24.5	24.9	0.31	1.07	OK < 5%
Beam Lv. 2	25.0	24.5	24.9	0.31	1.23	OK < 5%
Beam Lv. 3	25.1	25.0	24.9	0.29	1.19	OK < 5%
Beam Lv. 4	24.8	24.3	24.9	0.29	1.19	OK < 5%

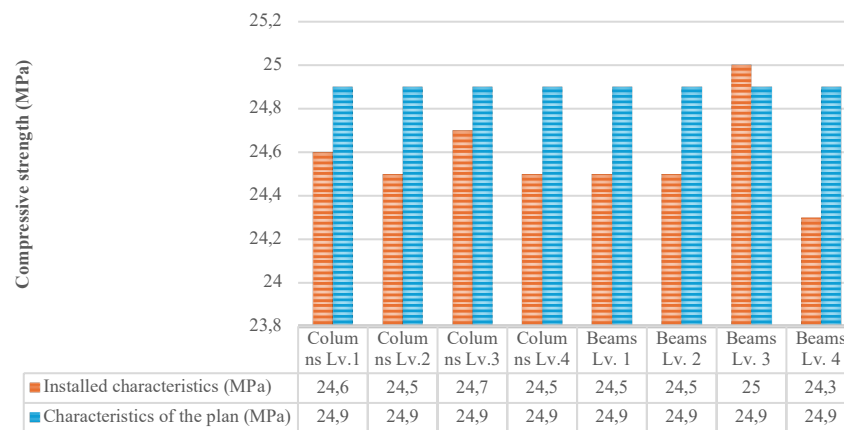


Figure 5. Comparison chart of concrete compressive strength

Figure 6 illustrates the percentage deviation between the planned concrete compressive strength and the actual strength obtained from field testing. The graph shows that the deviation values range from 1.0% to 1.3% for all structural elements. These values are significantly lower than the allowable tolerance limit of 5% according to SNI 2847:2019. The relatively stable pattern shown in the graph indicates that there are no significant fluctuations in concrete quality across different floors. This suggests that the concrete production, casting process, and quality control during construction were carried out consistently, resulting in a relatively uniform concrete quality throughout the structure.

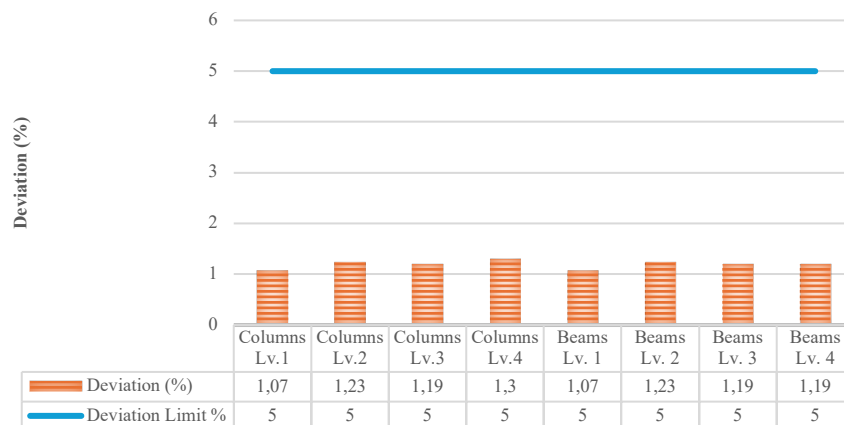


Figure 6. Concrete compressive strength deviation chart

Structural Analysis

Column Elements

Measurement of brick dimensions significantly influences the specific gravity and compressive strength of bricks (Sulistia, 2023). This is because the specific gravity and compressive strength values of bricks are analysed based on formula calculations by entering the volume value of the brick by knowing the length, width, and thickness of the brick (Al-Yasiri et al., 2026; Hashem et al., 2026; Roca et al., 2022; Sarwar et al., 2025; Wang et al., 2026; Wang & Abuel-Naga, 2025). Measurements were carried out on 3 types of bricks, each type of brick consisting of 3 pieces, so that the test specimens totalled 9 pieces. When the test was carried out, the type of brick sample was given the code A.1-A.3 for the acacia ash mixture, the code K.1-K.3 for the carbide welding ash mixture, and the code O.1-O.3 for conventional bricks.

Table 5. Comparison of Planned and Installed Column Properties

Parameters	Plan	Installed
Concrete quality, f_c	24.9 MPa	24.6 MPa
Steel quality, f_y	420 MPa	483.2 MPa
Main reinforcement	16 mm	16 mm
Column width	400 mm	400 mm
Column height	500 mm	500 mm
Shear reinforcement	10 mm	10 mm
Quantity	16	16
Area	3216 mm ²	3216 mm ²
β_1	0.85	0.85

Table 5 presents the comparison between the planned and installed column properties used in the structural evaluation. The reviewed column has dimensions of 400 mm × 500 mm with 16 longitudinal reinforcing bars of 16 mm diameter and transverse reinforcement of 10 mm diameter. Based on the reinforcement configuration, the calculated longitudinal reinforcement ratio is 1.61%, which satisfies the requirements specified in SNI 2847:2019. The comparison indicates that the installed concrete compressive strength is slightly lower than the planned value, while the reinforcing steel exhibits a higher yield strength than the design specification. These variations influence the axial–moment interaction capacity of the column. The analysis results show that the installed condition experiences an average reduction in column capacity of approximately 4.6% compared with the planned condition. To evaluate the seismic design requirement, the Strong Column Weak Beam (SCWB) principle was assessed by comparing the sum of column moment

capacities with the beam moment capacity at the beam–column joint. The results show that the SCWB ratio ranges from 1.64 to 2.00 for the upper joint and 1.48 to 1.81 for the lower joint. These values remain greater than 1.0, indicating that the SCWB requirement is satisfied. This means that the column capacity remains higher than the beam capacity, ensuring that plastic hinges are more likely to form in the beams rather than in the columns during seismic loading. Although the SCWB ratio in the installed condition is slightly lower than the planned design, the values still meet the seismic design criteria. This indicates that the variation in material properties has a limited effect on the structural safety margin and does not alter the intended collapse mechanism of the structure.

Design conditions

SCWB Capacity Comparison

A comparison between the planned and installed SCWB ratios shows a reduction of approximately 18% in the safety margin of the beam–column joint. This reduction is mainly caused by the slight decrease in concrete compressive strength in the columns and the increase in steel yield strength in the beams. However, the resulting SCWB ratios remain above the minimum requirement specified in seismic design provisions. Therefore, the structure still satisfies the ductility requirement, ensuring that the intended structural behavior under seismic loading conditions is maintained. Overall, the variation in material properties slightly influences the capacity of both column and beam elements. Nevertheless, the structural hierarchy between columns and beams remains unchanged, and the global structural performance is still within acceptable safety limits.

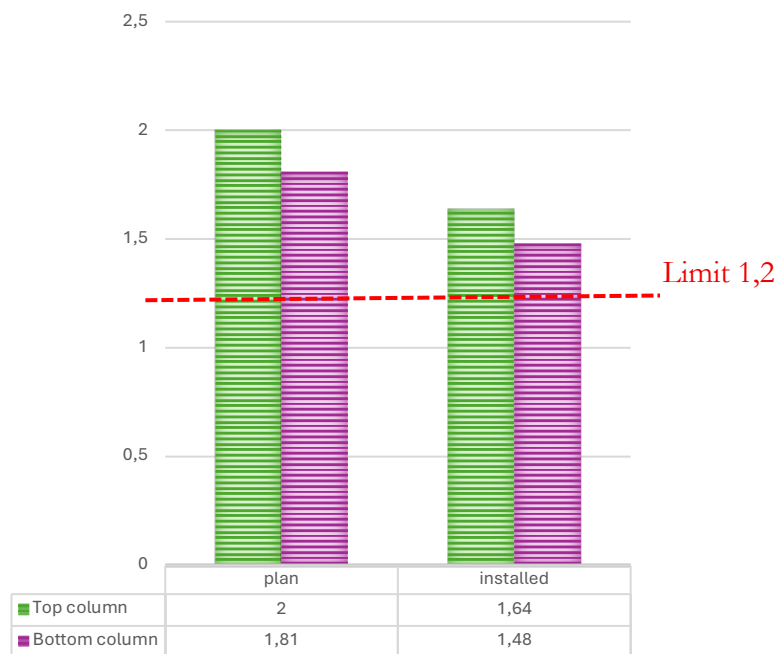


Figure 7. Comparison Ratio Chart

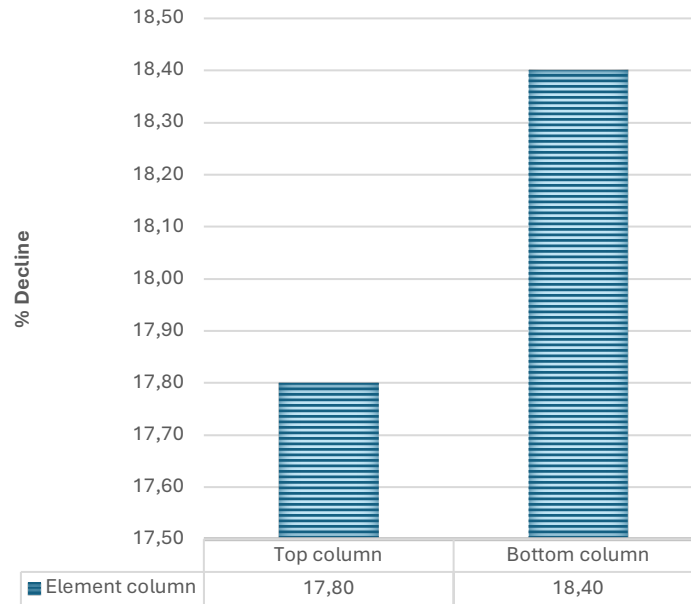


Figure 8. Capacity reduction chart

Beam Elements

Table 6. Comparison of Planned and Installed Beam Properties

Parameters	Planned	Installed
Concrete quality, f_c	24.9 MPa	24.8 MPa
Steel quality, f_y	420 MPa	483.2 MPa
Main reinforcement	16 mm	16 mm
Beam width	250 mm	250mm
Beam height	500 mm	500 mm
Effective height	422 mm	422 mm
Concrete cover	40 mm	40 mm
Shear reinforcement	10 mm	10 mm
β_1	0.85	0.85

The analyzed beam has a cross-sectional dimension of 250 mm × 500 mm with The analyzed beam section represents the typical reinforcement configuration used in the primary structural frame system. The beam was reinforced with double reinforcement consisting of 4D16 tensile reinforcement and 4D16 compression reinforcement, as specified in the design drawings. The calculated reinforcement ratio was $\rho = 1.61\%$, which satisfies the requirement of $\rho_{min} < \rho < \rho_{max}$ according to SNI 2847:2019. The bending strength of the beam was determined for both the proposed and the actually placed material conditions. The analysis shows that the installed beam exhibits a slightly higher flexural capacity compared to the design condition. This increase is primarily caused by the higher yield strength of the reinforcing steel obtained from the material test results.

The nominal moment capacity of the beam under the installed condition increases by approximately The nominal moment capacity increased from 147.95 kN·m to 168.34 kN·m, corresponding to an increase of approximately 3.3% compared to the planned condition. compared to the planned design value. This indicates that the beam is capable of resisting slightly higher bending moments than initially assumed in the design. Despite this increase in beam capacity, the column capacity remains higher, ensuring that the Strong Column Weak Beam

principle is not violated. The comparison between the planned and installed beam capacities is illustrated in Figure 9, which shows that the installed beam capacity curve lies above the planned capacity curve. This confirms that the actual reinforcing steel strength contributes to an increase in flexural resistance.

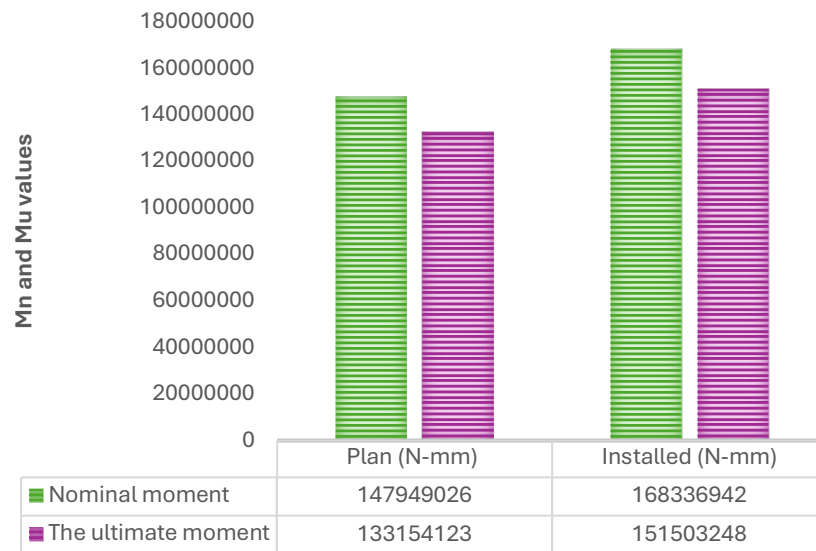


Figure 9. Comparison of capacity moments

The graph in Figure 9 shows the difference in the nominal moment capacity of the beams under the planned and installed conditions. The installed beam capacity actually experienced a slight increase, approximately 3.3% higher than the design. This increase was due to the actual reinforcement steel quality being higher than the nominal value (f_y). The graph shows that the installed beam capacity line is above the design line, which means that the beam is stronger than assumed in the design. However, because the column capacity is still higher, this increase does not violate the SCWB principle.

Discussion

The outcomes of testing the compressive strength of concrete in beams and columns elements showed an average value of 24.5–25.2 MPa, close to the planned quality of 24.9 MPa. The deviation was relatively small, only around 1.0–1.3%, and still well below the tolerance limit of 5% according to SNI 2847:2019. The relatively small variation in concrete compressive strength between floors indicates that the casting process and field quality control were adequately maintained during construction. According to Neville (1995), concrete quality variations greater than 5% can significantly reduce compressive capacity, but in this case, the deviation was small and did not have a significant impact on the performance of the structural elements. Analysis of the axial capacity of the columns shows an average decrease of 4.6% compared to the planned and actual material properties. Despite this decrease, the ratio of column capacity to beam capacity is still above 1, with values of 1.64–2.00 for the upper connection and 1.48–1.81 for the lower connection. This means that the Strong Column Weak Beam (SCWB) principle is still fulfilled. This is important because, according to Paulay & Priestley (1992), the SCWB The condition guarantees that plastic hinges develop in the beams instead of in the columns, so that the structure is able to behave ductile during an earthquake. The tensile test results for the reinforcing steel showed an actual yield strength (f_y) of approximately 483.2 MPa, which is higher than the nominal

strength of 420 MPa. This increase in steel quality resulted in a 3.3% increase in the nominal moment capacity of the beam. This increase is beneficial in terms of flexural strength, but it must still be monitored so that it does not exceed the column capacity. In this case, the column capacity is still greater than the beam, so the SCWB principle is not disrupted. This study is in line with Bruneau et al. (1998), which confirms that an increase in steel quality increases the flexural capacity of beams, but must be balanced with the column capacity. The SAP2000 modeling results show that the maximum inter-story displacement occurs on the 2nd floor at 34.38 mm, which is smaller than the allowable limit of 51.54 mm according to SNI 1726:2019. This indicates that the structure has adequate lateral stiffness, making it safe in terms of serviceability criteria. Additionally, the P-Delta effect evaluation results produced a stability coefficient θ of 0.01, which is much smaller than the limit of 0.1. This means that the effect of additional axial loads on lateral deformation is very small and does not cause instability. Overall, the actual quality of concrete and reinforcing steel in the structure differs slightly from the planned quality, but is still within safe limits. These differences do affect the capacity of the columns and beams, but the SCWB principle is still fulfilled, and the deflection between floors is still within specifications. Therefore, within the limitations of this study and based on the analyzed parameters, the structure still demonstrated acceptable performance in terms of strength and serviceability. This study emphasizes the importance of controlling material quality in the field to ensure that quality deviations remain under control, so that the performance of the structure does not deviate significantly from the design plan.

Conclusion

The results of this study indicate that the quality of the installed concrete in both columns and beams has an average compressive strength ranging from 24.5 to 25.2 MPa, with a deviation of approximately 1.0–1.3% from the planned value. This deviation is significantly lower than the allowable tolerance of 5% specified in SNI 2847:2019, indicating that the concrete quality meets the required standards and is well controlled during construction. The actual reinforcing steel quality shows a yield strength of approximately 483.2 MPa, which is higher than the nominal value of 420 MPa. This increase contributes to an improvement in the flexural capacity of the beams by approximately 3.3% compared to the planned condition. Although this enhances beam strength, it remains within acceptable limits and does not negatively affect the structural performance. On the other hand, the column capacity experiences a slight reduction of approximately 4.6% due to the variation in concrete compressive strength. Despite this decrease, the ratio of column-to-beam capacity remains greater than 1.0, ranging from 1.48 to 2.00. This confirms that the Strong Column Weak Beam (SCWB) principle is still satisfied. Although there is a reduction in the safety margin of approximately 18.1%, Although the safety margin decreased by approximately 18.1%, the column-to-beam capacity ratio still exceeded 1.0, suggesting that the SCWB requirement was satisfied. However, a comprehensive evaluation of structural ductility would require further assessment of detailing, confinement, and deformation capacity.

Furthermore, the structural analysis results using SAP2000 show that the maximum interstory drift is 34.38 mm, which is lower than the allowable limit of 51.54 mm based on SNI 1726:2019. The evaluation of the P-Delta effect also indicates that the stability coefficient (θ) is approximately 0.01, which is far below the limit of 0.1. This demonstrates that the structure has adequate lateral stiffness and stability under seismic loading. Overall, the differences between the planned and installed material properties slightly influence the structural capacity of both columns and beams. However, these variations remain within acceptable safety limits and do not compromise the overall structural performance. Therefore, the building structure can be considered safe in terms of both strength and serviceability under the applied loads, including earthquake effects.

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