UNIABUJA Journal of Engineering and Technology
https://ujet.uniabuja.edu.ng/
ISSN: 2714-3236 (Online); 2714-3228 (Print)
Volume 2, Issue 2, 2025; 72-82

# Compressive Strength Correlation of the Designed and As-Built Columns in Structures Using Non-Destructive Test Method- the Schmidt Rebound Hammer (Case Study: Kubwa, FCT-Abuja, Nigeria)

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***Abstract***
*Evaluating the compressive strength of concrete in new and existing buildings is important for assessing their structural integrity, for the early identification of structural issues, and for improving maintenance and safety measures. Columns in reinforced concrete buildings play a major role in load transfer and are most vulnerable to deficiencies in structural integrity, among other structural members. Consequently, this study analyzes the actual compressive strength (ACS) of columns in buildings in comparison to the designed compressive strength (DCS) through a non-destructive test (NDT) approach. The Data for this study was collected by carrying out the Schmidt Rebound Hammer (SRH) test on a sample size of 176 columns across 12 buildings in the study area. The rebound hammer type N was used as per BS EN 12504-2. This study established a power regression model, which was included in an MS Excel sheet to aid in the conversion of the rebound numbers. The highest, lowest, and average ACS were determined to be 20.035 MPa, 10.98 MPa, and 15.457 MPa, respectively; a significant variability in the compressive strength, with the average relative variation of -22.4%, was deduced, with building B11 indicating the strongest correlation with the DCS. Most building columns did not meet the DCS of 20 MPa, thus, it is recommended that the inadequate columns be recast under stringent supervision. For future projects in the study region, it was also recommended that concrete cubes be cast for laboratory checks of compressive strength.*

***Keywords:*** *Concrete column, compressive strength, non-destructive testing, Schmidt rebound hammer test, rebound number.*

## 1.0 Introduction

Compressive strength is a fundamental property of concrete considered when designing or remodeling structures (Atoyebi et al., 2019). Thus, accurately estimating the compressive strength of concrete is vital for guaranteeing the safety and reliability of buildings. This parameter determines the concrete's ability to withstand applied loads and maintain structural stability. As a result, assessing the structural capacity of new and existing buildings is critical in various scenarios, including in anticipation of seismic events, renovation requirements, adoption for various uses, and assessment after partial failure or structural damage (Pucinotti, 2013). Owing to the increasing incidence of building collapse, particularly in developing countries such as Nigeria, effective techniques for evaluating the structural capability of buildings have gained paramount importance. Nigeria has seen and continues to experience building collapses with varying degrees of fatality; recent estimates suggest that approximately 461 structures have fallen in the previous four decades (Gbonegun et al., 2021). In 2024 alone, as of July 14th, 22 cases of building collapse have been reported, with Abuja accounting for 18.18% of these incidents (Adaji et al., 2024). This can be attributed to a plethora of factors, one of which is the inappropriate utilization of building structural health monitoring data (Arum et al., 2006).

Traditional destructive testing techniques for assessing concrete quality have considerable disadvantages, such as concrete damage, high prices for crushing tests, and delays in carrying out the tests and getting actionable results. To address these challenges, researchers have created non-destructive testing techniques, such as the Schmidt rebound hammer (SRH), which can be used to evaluate the strength of structural building components, such as columns, slabs, and beams. The SRH test does not affect the intended performance of the structural part under consideration or the concrete quality (Ogunbayo et al., 2019). It is less expensive than other NDT methods, portable, and faster. The SRH test may be used to estimate concrete strength, allowing for fewer cores to be retrieved from buildings if the calibration is done correctly. In such instances, obtaining cores in situ may not be necessary (Aydin and Saribiyik, 2010). The results obtained from the SRH test may be influenced by a plethora of factors such as surface texture, type of hammer, concrete humidity, type of aggregate, mix ratio, cement type, and carbonation of the concrete (Ogunbayo et

Received: 07-01-2025 / Accepted: 02-05-2025 / Published: 24-05-2025

https://doi.org/10.70118/ujet.2025.0202.08

al., 2019; Jedidi M., 2020). To evaluate the effectiveness of the SRH test on high-strength concrete, Chen et al., (2023) advocated for the promotion of the SRH test due to its superior accuracy in determining the compressive strength of C50-C90 concrete samples. Pan et al. (2023) devised an intelligent rebound hammer system using the Internet of Things. The results of the study indicate that the system exhibits high accuracy and robust data transmission stability. The intelligent rebound hammer system improves test efficiency and data reliability in concrete strength assessment, analyzing the management and analysis of concrete strength data in real time.

Numerous investigations have proven the accuracy in predicting the compressive strength of concrete. The findings of Sanchez et al. (2014) showed that the SRH test may provide significant insights into concrete quality when calibrated for the type of concrete under evaluation. The study of Jolly et al., (2015) also discovered that the accuracy of rebound reading estimates depends on the device's calibration for a certain kind of concrete [12]. As a result, the reliability of the rebound hammer mechanism is highly related to its physical state and needs regular maintenance. Additionally, Aydin and Saribiyik (2010) compared calibration curves given by manufacturers to those acquired from an actual building. The two curves were roughly parallel, but they showed differing compressive strengths for the identical rebound hammer readings. The manufacturers' proposed curve yielded greater results than the concrete curves from an actual building. Sanchez and Tarranza et al. (2014) investigated the SRH test results of concrete samples exposed to brackish water. They discovered that the surface hardness of concrete affected the SRH measurements. The environmental conditions significantly influenced the compressive strength obtained from the rebound hammer test in comparison to the actual compressive strength derived from the direct compression test. Similarly, Celeronis et al. (2024) examined the use of the SRH in predicting the compressive strength of concrete in a seawater environment. This study revealed that a multitude of factors such as changes in temperature in the seawater environment, the calibration and maintenance of the rebound hammer device, the shorter drying period of the concrete samples after curing, the high amount of water retained in the samples, and the uneven distribution of force exerted by the plunger of the SRH device on the concrete surface greatly influenced the rebound number, leading to a high percentage error. Hence the SRH provided an inaccurate measure of the compressive strength of concrete due to these factors, although it is deemed acceptable for use if it is calibrated and regularly maintained to have good conditions Celerinos et al., (2024).

Vaibhav et al. (2022) performed the SRH test on concrete utilizing rice husk ash (RHA), and demonstrated that partial replacement with RHA led to an increase in the rebound number, thus causing a proportional increase in the compressive strength of the concrete. Furthermore, Brencich et al. (2013) studied the dependability of the rebound hammer test on concrete with various water-cement ratios that were all cured in normal, clean drinkable water. Their results revealed that surface irregularities in the concrete mixture had a significant influence on the rebound hammer readings. Hrischev et al., (2022) noted that when the compressive strength of cubic test samples was compared with that of the SRH test, the highest disparities were found between the destructive (maturity method) and non-destructive (SRH method) procedures at 1-day, which declines with age. The study of the calculated compressive strength values and the rebound hammer test results revealed a correlation between the two groups of data, indicating that the reliance is quite strong. A more recent study by Ali-Benyahia et al., (2023) compared the in-situ strength assessment accuracy of single NDT methods using prediction error RMSE in both BS EN 13791-2007 and BS EN 13791-2019, where both approaches yielded an adequate quality.

Researchers have conducted several studies to compare the dependability of the SRH to other non-destructive testing techniques. Kencanawati et al. (2021) compared the performance of the SRH and the ultrasonic pulse velocity (UPV) tests damaged concrete at different levels, characterized by decreased compressive strengths at varying percentages. It was deduced that the greater the level of damage, the greater the variation in the compressive strength obtained from the SRH. However, the readings of the UPV have a uniform correlation without being influenced by damaged concrete constraints. This implies that for concrete with elastic damage constraints, the use of the SRH must be complemented by additional techniques, such as the sampling core and the UPV. Co, (2019) developed equations that estimate the compressive strength of cylindrical concrete samples using SRH and UPV tests. It was concluded that the model derived by combining the UPV and SRH is far superior to the models derived by using each test alone since it gives a higher coefficient of determination ($R^2$). Furthermore, the experimental results revealed that estimated compressive strength using the rebound hammer was more accurate than that from the UPV. More recently, Abazarsa et al. (2024) conducted a study in which the SRH, UPV, and synthetic aperture radar (SAR) were employed to estimate the compressive strength of Portland cement concrete (PCC). All three non-destructive testing techniques showed correlated patterns, confirming the reliability of the SRH amongst other non-destructive testing methods.

In the study of Onyeka, (2020) the SRH test was compared with the pull-out test on concrete with 2

Received: 07-01-2025 / Accepted: 02-05-2025 / Published: 24-05-2025

https://doi.org/10.70118/ujet.2025.0202.08

mix ratios, and it was observed that the SRH gave more accurate results when compared to the pull-out method. Kazemi et al. (2019) investigated the compressive strength of concrete containing recycled concrete aggregate (RCA) using the Schmidt rebound hammer and core testing. The findings from this study show that a multivariable equation that uses the results from both testing methods can efficiently predict the compressive strength of concrete and is more reliable than single-variable equations based on the SRH test results. The SRH was evaluated as an overall mechanical quality indicator of self-compacting concrete (SCC) containing RCA in a study performed by Revilla-Cuesta et al. (2022). Here the rebound number was represented as a combination of four mechanical properties modified using multiple regression. It was deduced that the rebound number from the SRH test forecast every mechanical property, extending its applications in structural health monitoring (SHM) where a thorough evaluation of the mechanical behaviour of SCC and RCA is needed. These studies have proven the reliability of the SRH, thus making it the ideal tool for this study.

This study, however, aims to access the actual compressive strength of columns in buildings in comparison with their designed compressive strength to understand the quality of concrete in the study area. The focus on Kubwa as a case study in Abuja, Nigeria is due to its infrastructure growth, which has resulted in the construction of newer buildings and remodeling of existing RC buildings. Additionally, structural failures, including two building collapses in recent times have occurred (Nwachukwu, 2024; The Structural Engineer, 2022). The results from this study will provide localized data that can inform construction practices in the region and, by extension, other parts of Abuja. While previous studies by Jedidi, (2020) and Ogunbayo et al. (2019) highlighted the variability in compressive strength due to various factors, this paper uniquely contributes by offering detailed empirical evidence on the extent of these variations and their implications for structural integrity.

## 2.0 Materials and Methods

The primary data utilized for this research were obtained from SRH tests conducted under El-tojje and Associates Ltd. The research structural elements selected consisted of columns in twelve (12) reinforced concrete buildings in Kubwa, Abuja. The buildings tested in this study fall under business and professional use (Group B) and residential use (Group H) as categorized by the National Building Code Building Use groups. As shown in Figure 1 below, 9(75%) of the 12 buildings were under Group H, while only 3(25%) fell under Group B. This distribution can be attributed to the fact that the study area, Kubwa, is primarily residential, attracting a growing population and serving as an affordable residential location within the Federal Capital Territory, Abuja. Each building has its structural peculiarities, ranging from column layout and spacing variations, column sizes, concrete surface conditions (finished or unfinished), and construction detailing. Due to field constraints, not all columns in each building were tested, but a minimum of 6 test columns were maintained for all buildings to maintain data reliability. In some instances, access to some columns was limited. In other cases, buildings with a high density of columns, a random sampling approach was employed to ensure a reasonable and representative assessment of the compressive strength of columns as supported by Dhaval et al (2023). These measures were implemented to ensure that the data obtained from the SRH test was accurate and representative of the structural condition, despite the limitations encountered on site. All 12 buildings are low-rise buildings with a maximum of two (2) floors, some of which were under construction at the time of testing.

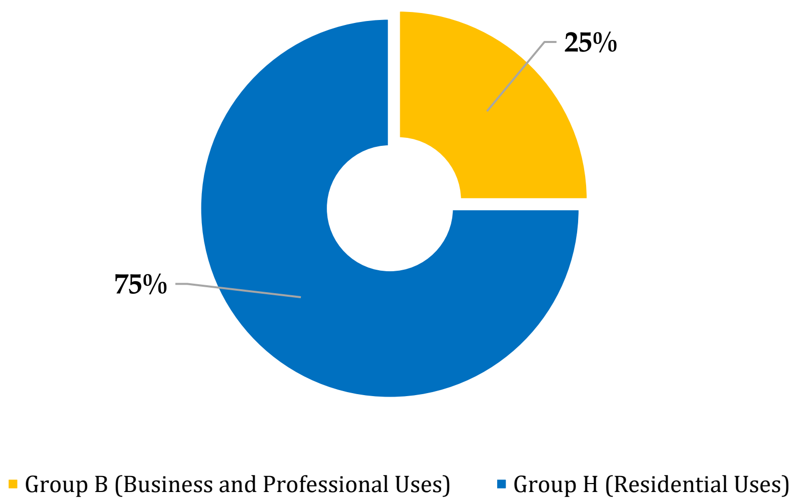


Figure 1: Distribution of building use groups according to the national building code

Received: 07-01-2025 / Accepted: 02-05-2025 / Published: 24-05-2025

https://doi.org/10.70118/ujet.2025.0202.08

A standard SRH type N (Proceq, 2006) was used in the test; ten (10) rebound number readings over an area within 300mm square with impact points, at least 25mm from each other or the edge, was taken per column. Additionally, care was taken to avoid visibly defective column concrete surfaces showing honeycombs, cracks, voids, or spalled regions, as these could compromise the accuracy and reliability of the data from the SRH test in accordance with the BS EN 12504-2:2021. Other data used in this work include the calibration curve of the SRH model used (see Figure 2 below), general notes of these buildings, including their designed compressive strength, column types, and other intrinsic details obtained from the structural drawings and visual inspection.

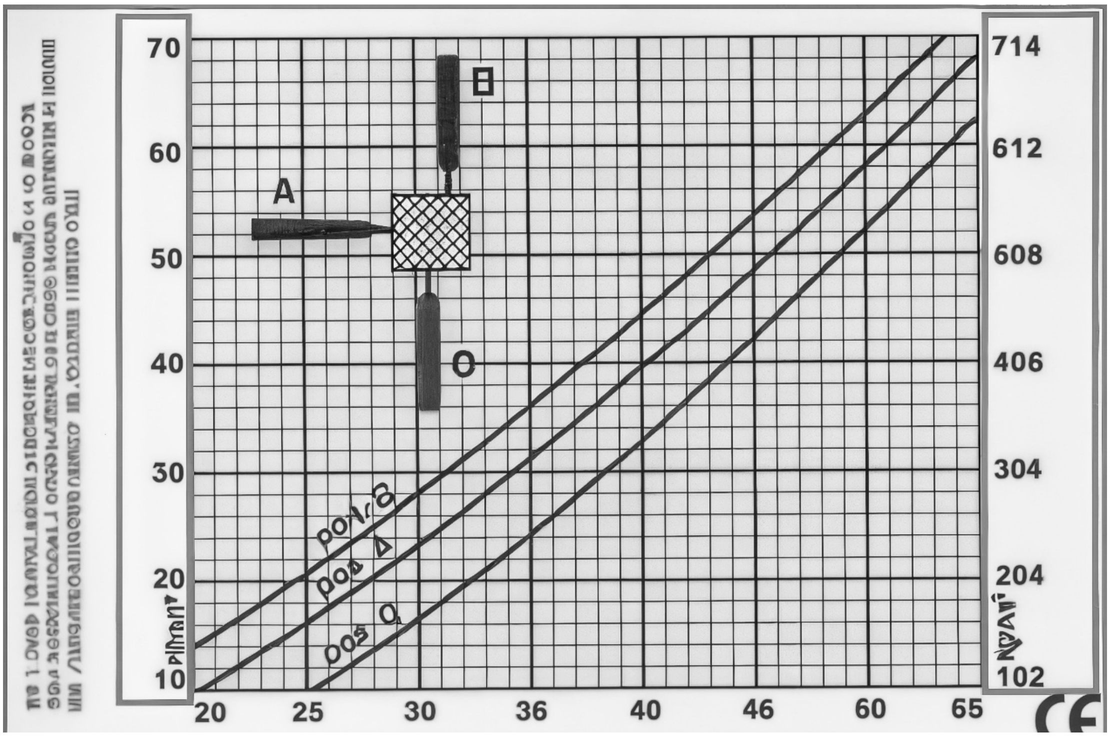


Figure 2: Rebound number conversion curve for the Rebound Hammer Model used in the study

A total of 176 columns were tested with cross-sections of 230mm x 230mm, 230mm x 300mm, and 230mm x 450mm. Notably, all 12 Buildings had a DCS of 20MPa. To mitigate the time and error associated with converting the rebound numbers to their equivalent compressive strengths, a linear and power regression model was developed based on the calibration table for the SRH type N. A conversion model is always necessary for evaluating concrete strength, as it establishes the relationship between the values obtained from NDT tests and the actual compressive strength of concrete (Alwash et al., 2015). In the development of conversion models, regression analysis has been employed by other researchers to establish the reliability of the SRH (Kazemi et al., 2019; Sajid et al., 2016; Hidayat et al., 2024; Singh et al.,2024), where the best curves were used to estimate the compressive strength of concrete. A similar method was employed in this study. A linear and power regression model was developed based on the calibration curve for SRH type N, as shown in equations (i) and (ii),

$$Y1 = 1.5399X - 21.968 \quad \text{(i)}$$

$$Y2 = 0.0243X^{2.0178} \quad \text{(ii)}$$

where:
X- Rebound number
Y1- Equivalent Compressive Strength from the linear model
Y2- Equivalent Compressive Strength from power model

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https://doi.org/10.70118/ujet.2025.0202.08

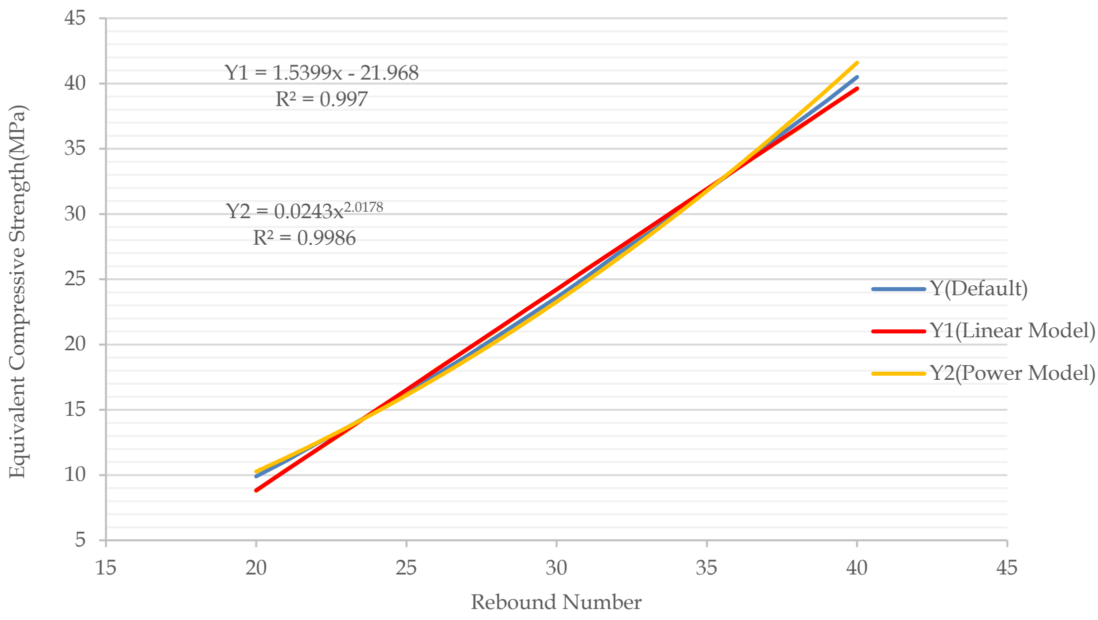


Figure 3: Regression model for converting Rebound Numbers to their equivalent compressive strength

Figure 3 above shows that the power model is the most accurate for estimating the equivalent compressive strength, with the highest coefficient of determination (R2) of 0.9986. This suggests an excellent fit for predicting the equivalent compressive strength. The reliability of the power model is reinforced by the study of Pereira et al. (2018), who proposed using power models to represent the relationship between the rebound number and compressive strength, particularly when considering existing structures. Therefore, the power model was employed in the MS Excel conversion sheet for this study. It should be noted that the Power model and the MS Excel conversion sheet have limitations set to a maximum average rebound number of 40. This limitation is based on the observation that structures with such high compressive strength, typically categorized as mega-structures, often undergo more stringent quality control measures during construction. Consequently, conducting SRH tests on such buildings is generally unnecessary, as other advanced non-destructive testing methods may be employed.

The Power Model was thus used in an MS Excel conversion sheet to facilitate the conversion. The statistical software IBM SPSS was used to make further inferences using statistical indices such as the coefficient of variation, Pearson's correlation coefficient, and relative variation. Multiple line charts were created to present the results effectively.

## 3.0 Results and Discussion

### 3.1 Average ACS

The highest, lowest, and average actual compressive strengths of 20.035MPa, 10.98MPa, and 15.457MPa were deduced, as shown in Table 1 below, with the highest and lowest values obtained from Building B11 and Building B8. Figure 6 shows that only building B11 meets the designed compressive strength of 20MPa. The average actual compressive strength falls below the minimum required for mid-rise buildings. Figures 4 and 5 show the relationships between the compressive strengths of the different buildings considered in this study. The compressive strength of each floor was 16.228MPa, 15.697MPa, and 14.1MPa for the ground floor, first floor, and second floor, respectively, which decreased with an increase in the floor, with the second floor having the weakest columns. This trend correlates with the findings of Atoyebi et al. 2023 and suggests a reduction in concrete quality with an increase in floors.

Received: 07-01-2025 / Accepted: 02-05-2025 / Published: 24-05-2025 
https://doi.org/10.70118/ujet.2025.0202.08

Table 1: Actual compressive strength of columns

| Building No. | ACS (MPa) | | | | DCS (MPa) |
|---|---|---|---|---|---|
| | GF | FF | SF | Average | |
| B1 | 20 | 17.88 | - | 18.94 | 20 |
| B2 | 14.49 | 17.76 | - | 16.125 | 20 |
| B3 | 17.47 | - | - | 17.47 | 20 |
| B4 | 17.57 | 15.92 | 13.2 | 15.563 | 20 |
| B5 | 15.31 | 10.14 | - | 12.725 | 20 |
| B6 | 16.08 | 17.23 | 13.87 | 15.727 | 20 |
| B7 | 10.3 | 12.4 | 12.4 | 11.7 | 20 |
| B8 | 10.98 | - | - | 10.98 | 20 |
| B9 | 21.1 | 13.5 | 11.13 | 15.243 | 20 |
| B10 | 18.88 | 16.3 | 19.9 | 18.36 | 20 |
| B11 | 19.93 | 20.14 | - | 20.035 | 20 |
| B12 | 12.62 | - | - | 12.62 | 20 |
| **Average** | **16.228** | **15.697** | **14.1** | **15.457** | **20** |

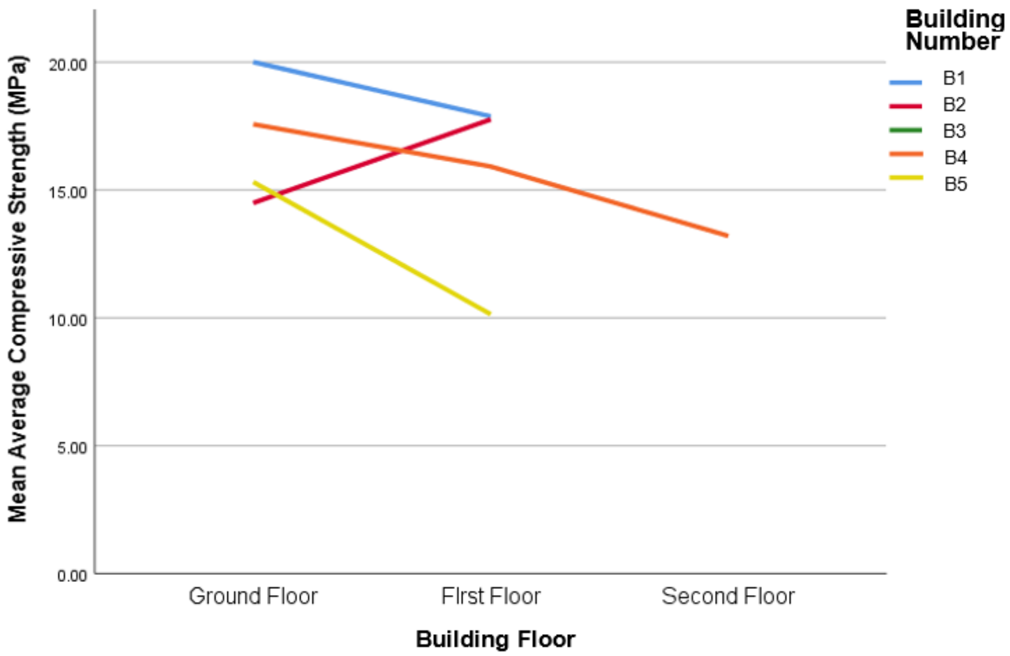


Figure 4: Relationship between the actual compressive strength for buildings B1-B5

Received: 07-01-2025 / Accepted: 02-05-2025 / Published: 24-05-2025
https://doi.org/10.70118/ujet.2025.0202.08

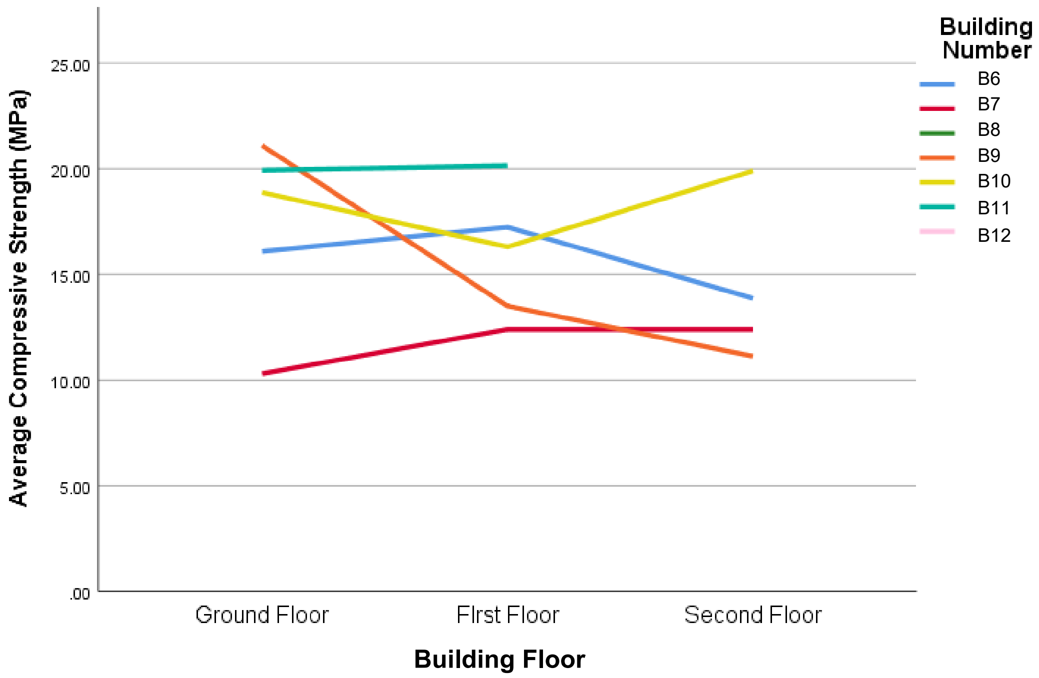


Figure 5: Relationship between the actual compressive strength for buildings B6-B12

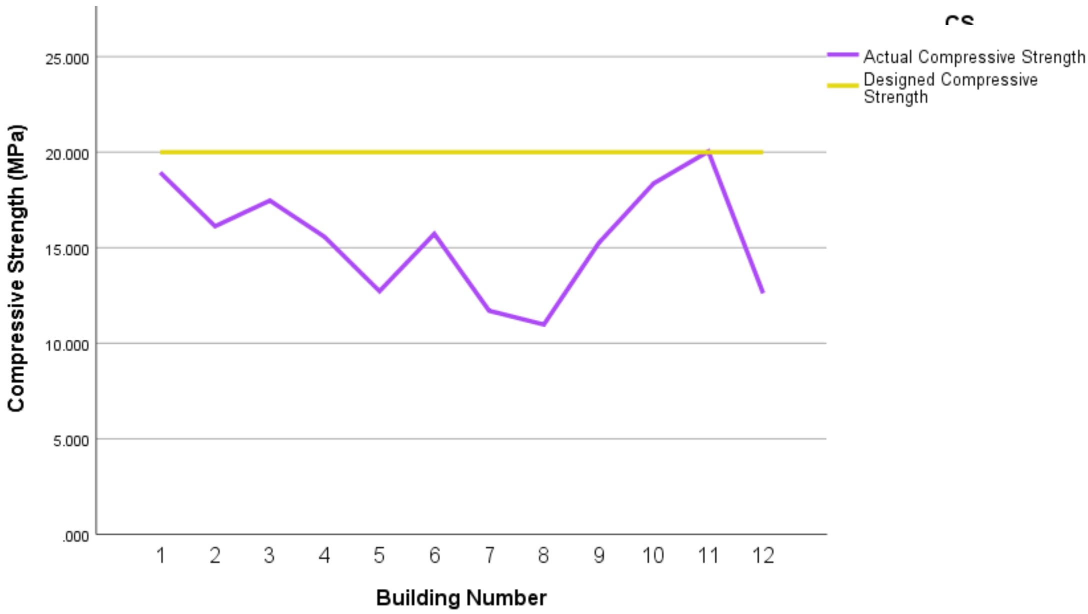


Figure 6: Multiple line chart showing the relationship between the ACS and the DCS

### 3.2 Coefficient of variation

The compressive strengths of the columns tested generally vary widely, as indicated by an average coefficient of variation (CV) of 15.77%, as shown in Table 2 below. This implies that the actual compressive strengths are far from the mean values. Building B3 had the lowest CV of 6.03%, whereas building B9 had the highest CV of 25.217%.

Among the floors, the ground floor presented the highest dispersion from the mean, with a CV of 16.465%. The CV of the ground, first, and second floors were 16.465%, 15.38%, and 14.792%, respectively. This variability in the concrete quality can be attributed to the result of one or more of the following: inconsistent concrete mix, poor construction practices, poor supervision and quack professionals(Shrestha et al. 2024; Uguru et al. 2022).

Received: 07-01-2025 / Accepted: 02-05-2025 / Published: 24-05-2025

https://doi.org/10.70118/ujet.2025.0202.08

Table 2: Actual compressive strength descriptive statistics

| Building No | Floor | ACS | Variance | Standard Deviation | CV |
|---|---|---|---|---|---|
| B1 | F1 | 20.00 | 22.36 | 4.73 | 23.64 |
| B1 | F2 | 17.88 | 3.05 | 1.74 | 9.76 |
| B2 | F1 | 14.49 | 8.26 | 2.87 | 19.83 |
| B2 | F2 | 17.76 | 29.05 | 5.39 | 30.35 |
| B3 | F1 | 17.47 | 1.11 | 1.05 | 6.03 |
| B4 | F1 | 17.57 | 11.93 | 3.45 | 19.67 |
| B4 | F2 | 15.92 | 10.77 | 3.28 | 20.62 |
| B4 | F3 | 13.20 | 0.38 | 0.62 | 4.69 |
| B5 | F1 | 15.31 | 10.49 | 3.24 | 21.16 |
| B5 | F2 | 10.14 | 0.26 | 0.51 | 4.99 |
| B6 | F1 | 16.08 | 4.15 | 2.04 | 12.66 |
| B6 | F2 | 17.23 | 3.66 | 1.91 | 11.10 |
| B6 | F3 | 13.87 | 2.29 | 1.51 | 10.91 |
| B7 | F1 | 10.30 | 0.38 | 0.62 | 6.02 |
| B7 | F2 | 12.40 | 0.00 | 0.00 | 0.00 |
| B7 | F3 | 12.40 | 12.50 | 3.54 | 28.51 |
| B8 | F1 | 10.98 | 3.84 | 1.96 | 17.84 |
| B9 | F1 | 21.10 | 22.74 | 4.77 | 22.60 |
| B9 | F2 | 13.50 | 25.45 | 5.04 | 37.37 |
| B9 | F3 | 11.13 | 3.04 | 1.74 | 15.68 |
| B10 | F1 | 18.88 | 7.94 | 2.82 | 14.93 |
| B10 | F2 | 16.30 | 3.92 | 1.98 | 12.15 |
| B10 | F3 | 19.90 | 7.95 | 2.82 | 14.17 |
| B11 | F1 | 19.93 | 9.81 | 3.13 | 15.72 |
| B11 | F2 | 20.14 | 5.94 | 2.44 | 12.10 |
| B12 | F1 | 12.62 | 4.86 | 2.20 | 17.48 |
| **Average** | | **15.63** | **8.31** | **2.52** | **15.77** |

### 3.3 Pearson's correlation coefficient

Within the context of this research, Pearson's correlation coefficient provides a measure of the correlation between the compressive strength of the columns of the different floors. The results indicated that there is a weak, negative, and insignificant correlation between the compressive strengths of the columns on the different floors. This implies that there is a large variation in concrete quality as one transitions from one floor to another.

### 3.4 Relative variation (RV)

The designed compressive strength for all the buildings was 20MPa. The variation in the actual compressive strength from this value was calculated as shown in Table 3 below. The average relative variation for all twelve (12) buildings is -22.4%. This finding indicates that the actual compressive strength of these buildings is 22.4% lower than the designed compressive strength of 20MPa, reflecting a consistent underperformance in the columns tested compared to their design specifications.

Building B8 shows the highest relative variation with a value of -45.1%, and building B11 exhibits a nearly negligible variation of 0.15%, which indicates the strongest compressive strength correlation. Building B11 is a 1-storey residential building, and upon visual inspection.

Despite these variations in buildings, a consistent trend emerges across all buildings analyzed. On average, there is an increase in relative variation from the ground floor to the second floor, with the second floor exhibiting the highest relative variation. This suggests that the lower floors are less susceptible to variations in concrete quality, whereas the upper floors demonstrate a lower correlation with the designed compressive strength.

Received: 07-01-2025 / Accepted: 02-05-2025 / Published: 24-05-2025

https://doi.org/10.70118/ujet.2025.0202.08

Table 3: Relative variation in the actual compressive strength to the designed compressive strength

| **Relative Variation** | | | | | |
|---|---|---|---|---|---|
| **Building No.** | **GF** | **FF** | **SF** | **Average** | **Average (%)** |
| **B1** | 0.000 | -0.106 | - | -0.053 | -5.3 |
| **B2** | -0.2755 | -0.112 | - | -0.19375 | -19.375 |
| **B3** | -0.088 | - | - | -0.088 | -8.8 |
| **B4** | -0.122 | -0.204 | -0.34 | -0.222 | -22.2 |
| **B5** | -0.235 | -0.493 | - | -0.364 | -36.4 |
| **B6** | -0.196 | -0.139 | -0.307 | -0.214 | -21.4 |
| **B7** | -0.485 | -0.38 | -0.38 | -0.415 | -41.5 |
| **B8** | -0.451 | - | - | -0.451 | -45.1 |
| **B9** | 0.055 | -0.325 | -0.444 | -0.238 | -23.8 |
| **B10** | -0.056 | -0.185 | -0.005 | -0.082 | -8.2 |
| **B11** | -0.004 | 0.007 | - | 0.0015 | 0.15 |
| **B12** | -0.369 | - | - | -0.369 | -36.9 |
| **Average** | **-0.202** | **-0.215** | **-0.295** | **-0.224** | **-22.4** |
| **Average (%)** | **-20.2** | **-21.5** | **-29.52** | | |

## 4.0 Conclusion

This study analyzed the compressive strength of columns in buildings in comparison to their designed compressive strength using the Schmidt rebound hammer. From this study, the following conclusions can be drawn:

- The Schmidt rebound hammer test conducted on the 176 columns yielded rebound numbers that were collated and converted to their respective compressive strengths using the power model incorporated into a Microsoft Excel sheet, increasing accuracy and efficiency.
- The highest, lowest, and average compressive strengths deduced were 20.035MPa, 10.98MPa, and 15.457MPa, respectively, with only building 11 meeting the designed compressive strength of 20Mpa. A progressive compressive strength decrease was exhibited from the ground floor to the first floor to the second floor.
- Furthermore, from the compressive strength analysis done on SPSS, the coefficient of variation (COV) was 15.77%. Pearson's correlation coefficient revealed a weak, negative, and insignificant correlation between the compressive strength of columns on each floor. The Relative variation was 22.4% with an increasing value from the ground floor to the first floor to the second floor. This suggests that the lower floors are less susceptible to variations in concrete quality, whereas the upper floors demonstrate a lower correlation with the designed compressive strength.
- The compressive strength of the RCC columns is not adequate and remedial measures should be taken by recasting to make them adequate. The observed disparities between the actual and designed compressive strengths emphasize the impact of factors affecting the concrete mix quality according to the specified grade.

The observed disparities between the actual and designed compressive strengths emphasize the impact of factors affecting the concrete mix quality according to the specified grade; further investigations into the root causes of these variations can be performed. Furthermore, the scope of this study can be extended to encompass other structural elements such as slabs, beams, and column bases to assess their compressive strength integrity. Furthermore, expanding the study's geographical coverage to a broader region would increase its significance in shaping future design and quality control practices. The Microsoft Excel Conversion Sheet, developed using the power model for the conversion of rebound numbers into corresponding compressive strengths, will serve as a valuable tool for structural engineers, especially when dealing with a vast dataset of rebound numbers for larger-scale testing.

Received: 07-01-2025 / Accepted: 02-05-2025 / Published: 24-05-2025

https://doi.org/10.70118/ujet.2025.0202.08

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Received: 07-01-2025 / Accepted: 02-05-2025 / Published: 24-05-2025 
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Received: 07-01-2025 / Accepted: 02-05-2025 / Published: 24-05-2025
https://doi.org/10.70118/ujet.2025.0202.08