Effect Of Concrete Mix Design On Non-Destructive Test Results For Strength Evaluation

Rakesh Chandrashekar[1,*], Suneel Donthamsetty[2],V. Arun Kumar [3], Manish Gupta[4], Yalla Jeevan Nagendra Kumar[5], Neeraj Chahuan[6]

[1]Department of Applied Sciences, New Horizon College of Engineering, Bangalore, India.

[2]Department of Mechanical Engineering, Narasaraopeta Engineering College, Narasaraopet, Andhra Pradesh - 522601, India.

[3]Department of Electronics and Communication Engineering, MLR Institute of Technology, Hyderabad, Telangana, India.

[4]Lovely Professional University, Phagwara, India

[5]Department of Information Technology, Gokaraju Rangaraju Institute of Engineering and Technology, Bachupally, Hyderabad, Telangana, India.

[6]Lloyd Institute of Engineering & Technology, Greater Noida, Uttar Pradesh 201316

Abstract- In ND methods of durability monitoring, a wide area of applications is concerned due to its possibility of assessment conditions without causing damage to structures. Those methods are also being fine-tuned to create the connection of ND results to durability indicators of concrete under challenging environmental conditions such as marine exposure where gradients in water and chlorides significantly accelerate the deterioration. The non destructive methods such as ultrasonic pulse velocity and rebound hammer tests help in analysing the on-site behaviour of materials without causing any structural damage. More reliable descriptions of the in-situ behavior of in-place materials are available in ND techniques, like those of. Relations between UPV and core and cylinder compressive strengths together with rebound hammer results is being studied in this paper. The properties are compared to modulus of elasticity, bond strength, and cube compressive strength, which shows how rebound hammer tests performs when compared with other measures. An experimental process based on combination of ND and DT techniques to evaluate various grades of concretes, including M20 grade has been studied. For the slab samples, cores from each were obtained and were tested besides 100x200 mm cylinders and 150x150x150 mm cubes for testing compressive as well as pull-out strengths. Various methods such as UPV and rebound hammer showed good promising results for evaluating durability as well as integrity of a structure. The results confirm that the robust integration of ND methods with destructive methods for assessing concrete properties have underlined value in preserving the structural heritage and enhancing the long-term monitoring of the durability of concrete in adverse environments.

1. Introduction

One of the key problems that researchers and engineers around the world are trying to find a solution for now is the in situ strength determination of existing structures. Compressive strength in situ is one of the major parameters to consider when appraising the safety of a reinforced concrete structure. Study of "ancient" structures reveals all the main physical properties of concrete and its state of conservation, along with the technologies and materials that were in use at the time of construction [1]. The estimation of the concrete's strength is necessary for seismic strengthening design and to determine the seismic capacity of an existing structure. For this estimate compressive tests performed on the cylindrical specimens derived from structural elements are quite often used. Besides these destructive tests some non-destructive tests could be applied. That enhances the information provided and decreases costs for quality assurance [2]. Recent innovative code developments also clearly provide principles for static strengthening of already existing structures about their further behavior in service and with respect to safety.

---

*Corresponding author: chandrashekarrakesh0@gmail.com

The extent of knowledge determines the degree, nature, and intensity of in situ testing that occurs. These are mainly three in number: KL1 - limited; KL2 - normal; KL3 - full. By determining the level of knowledge, there can also be methods used by the acceptable analytical, partial safety factor values, among others. The Italian code suggests that the required specimens are obtained by coring structural elements to get an approximation of the mechanical properties of the material. Non-destructive test methods such as SonReb, the Schmidt hammer test (Rebound), and the Ultrasonic Pulse Velocity test (UPV) are allowed by European as well as Italian standards, but only in combination with a destructive test [3-6]. These methods using non destructive methods can now be effectively utilized, it is because a correlation has been established between in-situ compressive strength, either calibration curves or results derived from indirect approaches for the specific concrete under evaluation. Hence, the in-situ compressive strength of concrete can also be estimated through compression tests performed on cores extracted from structural elements [7]. 359 cores were subjected to a battery of destructive laboratory tests to establish the average strength of in-situ concrete. A numerical analytical formula was applied to calculate the typical in-situ compressive strength of the concrete. The present formulation may provide a reasonable estimate of the in-situ characteristic concrete compressive strength when the application results were compared with the other equations reported in the technical literature [8]. The important thing that should be addressed to a reinforced concrete building's seismic damageability or structural resistance. It is to classify the material used in terms of being "ancient" or historical structure as time spans will make the mechanical properties unpredictable [9-10]. Additionally, because significant historical values are often tagged to these structures, possible destructive tests, such as cores, may be lessened in number. Generally speaking, non-destructive methods are only justified where the compressive strength of cores that have been extracted from the structure is correlated directly with the results from NDT tests [11]. The results of several non-destructive tests are provided together with a wealth of information gathered from a sizable database of testing done on existing RC structures built in the Tuscan area of Italy between 1950 and 1980. According to the report, a comprehensive campaign of on-site testing is necessary to achieve the appropriate level of dependability of the compressive concrete strength [12]. It is a common fact that a proper strength of the concrete must be ascertained for the estimation of seismic performance of the existing buildings [13-14]. It has been demonstrated that formulas found in technical literature produce values that differ from the real ones. However, the results obtained with the SonReb method are reasonably close to the real ones when calibrated by means of the strength of cylindrical specimens (cores) extracted from different buildings. The value of application was typically high for existing RC buildings. Many existing buildings in Tuscany have their coefficients of variation calculated by Cristofaro and other researchers [15–17]. Furthermore, the fact that an extension of the spread of compressive strength based on adjustment of an ad hoc correlation curve in a single building of the SonReb method implies that significant reduction of coefficient of variation does not occur together with an increase in the number of data being considered [18]. The benefits and applications of using non-destructive testing (NDT) measurements to determine the strength of concrete on-site are discussed by Breysse. The study was conducted based on a critical analysis of the existing models, along with a review of experimental data collected by different authors in both lab and on-site settings [19]. The main determinants of the strength estimate's quality were found. Several empirical strength-NDT models were examined, but two NDT methods—UPV and Rebound—were given particular priority. It was found that the measurement error significantly impacted the estimate quality more than the model error did [20]. The number of unknown parameters was significantly decreased in the concrete assessment method that the author suggested [21]. On the basis of an earlier double power law model that identified a single parameter, a recommendation was made and the main calibration problem in the SonReb combined approach was resolved. The author demonstrates that the quality of the evaluation can be maintained while drastically lowering the number of calibration cores [22].

In this context, the present study introduces a novel integrated experimental methodology that systematically correlates rebound hammer and ultrasonic pulse velocity (UPV) measurements with destructive test results-including cylinder, core, and cube compressive strengths-for M20 grade concrete. While prior research has often focused on higher-strength concretes or individual NDT techniques, this work provides a comprehensive comparative analysis for a commonly used structural grade, with explicit consideration of mix design parameters such as aggregate absorption, specific gravity, and moisture content. By validating the combined application of rebound and UPV tests, this study offers a practical and reliable framework for in-situ strength assessment, contributing to improved non-destructive evaluation protocols for existing concrete structures, especially in durability-critical environments such as marine exposures.

2. Methodology

Cement, fine and coarse aggregates, and water in the proper proportions combine to form concrete. It is a commonly used building material because its constituents are affordable and easily accessible. Additionally, concrete can be moulded into any desired size or shape while it is still fresh. The most crucial characteristics of concrete are its strength and durability, particularly in structural applications. Thus, the compressive strength of concrete should be measured before it is subjected to the expected loads. Both destructive and non-destructive testing techniques can be used to analyze the compressive strength of hardened concrete. In this research work, NDT techniques were used for the assessment of compressive strength of the concrete, and the link of NDT techniques to the compressive strength also identified. Due to which the concrete slabs, cylinders, cubes, and cube specimens with the bars incorporated into them were cast. Grade 43 OPC cement is used for specimen casting. Fine aggregate is made from the readily available river sand in the area. The coarse aggregates used were 20 mm and 10 mm, both of which were easily accessible locally. Using IS10262, the concrete mix design for grades M20 was created. For this experimental work, the mix proportions specified were used. The following are the characteristics of the material used:

Table 1 Material used for this experimental work

Material Property	**Value**
Maximum Aggregate Size	20 mm
Type of Cement	43 Grade OPC Cement
Cement Specific Gravity	3.15
Fine Aggregate Specific Gravity	2.77
Coarse aggregate specific gravity	2.8
Water Absorption by Coarse Aggregates	0.5%
Absorption of Water by Fine Aggregate	1.1%
Free Moisture Content	
i) Coarse Aggregate	Nil
ii) Fine Aggregate	1%

Table 1 offers the required details of the material characteristics, which were used for conducting the concrete experiment, in respect to the critical parameters determining mix design, strength, and workability. For the mix, maximum aggregate size is 20 mm; the above two parameters are strongly linked and determine the workability and ultimate compressive strength. Larger aggregates generally decrease the water demand of the mix but also tend to reduce the achievable strength due to less uniform bonding between the cement paste and aggregate. The 43 Grade OPC used in the mix has a specific gravity of 3.15, indicating its density relative to water. This is an important parameter to determine the volume proportions correctly in the mix design. Similarly, the specific gravities of the coarse and fine aggregates, measured at 2.77 and 2.8, respectively, are important for determining the relative proportion of these materials in the mix. The specific gravity values are essential to obtain the appropriate density and mechanical performance of the concrete. Water absorption rates of aggregates also play a very critical role in controlling the mix's water content. This coarse aggregate has a 0.5% very low absorption rate, but the fine aggregate has been recorded to have a somewhat higher rate of 1.1%. These deviations require careful adjustments in terms of water content to have the desired water-to-cement ratio to avoid such inconsistencies and prevent over hydration or under hydration of cement paste. The free moisture content of the aggregates contributes to the overall mix also. Fine aggregate has a free moisture content of 1%, whereas in coarse aggregate, there is zero free moisture content (0%). Such values are important parameters for fine-tuning the mix design to work out the balancing act of workability against strength (Fig. 1). Proper accounting for these material properties is important to bring about durable, workable, and strong concrete mixes that will meet structural requirements under a variety of environmental exposures.

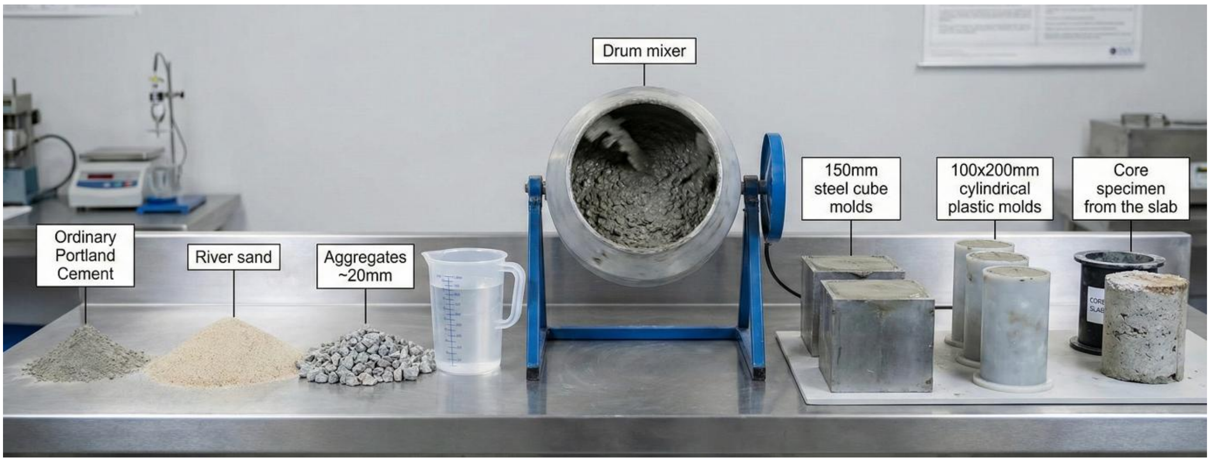

Fig. 1. Raw materials (43 Grade OPC, fine aggregate, coarse aggregate), mixing process, and freshly cast specimens (cubes, cylinders, and core) used in the experimental program

3. NDT (Non-Destructive Test) Methods

The research era is fast realizing the benefits of nondestructive testing for both engineering and practical applications in a sustainable manner. In recent years, using nondestructive testing (NDT) to assess the condition of damaged concrete structures has gained popularity. The term "nondestructive test" refers to an examination that is carried out without jeopardizing the structural or mechanical integrity of a part, material, or assembly. The use of NDT test will enable testing products, assemblies, and components without a change in functionality. This NDT test will determine if the quality and strength of concrete. The strength, porosity, voids, width and depth of cracks, inclination, and concrete are measurable by determining the material's ultrasonic pulse velocity. In the case of measuring ultrasonic pulse velocity precisely, it will consider that the surface is smooth at the point where the test is being carried out. As long as the transducers are pressed against the surface, and the coupling medium is put on smoothly, most concrete surfaces should have good acoustical contact (Fig. 2). Before measuring pulse velocity, the concrete surface must be smoothed out if it is rough or uneven; otherwise, the measurement will not be accurate. The identity and modulus of elasticity of ultrasonic pulse velocity concrete are its main determinants. These are the key factors that are influenced by the ingredients and proportions of the mixture and the methods used for pouring, compacting, and curing the concrete.

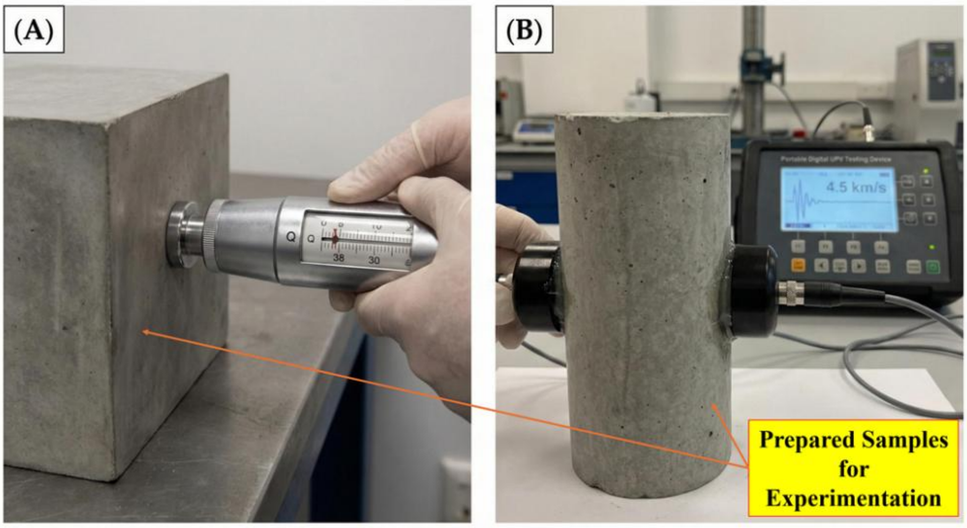

Fig. 2. Application of non-destructive testing methods: (A) Rebound hammer test on a concrete cube, and (B) Ultrasonic Pulse Velocity (UPV) test on a concrete cylinder.

4. Results

The use of non-destructive (ND) methods for durability monitoring and diagnosis is becoming more and more important in the context of structural heritage preservation. A strategy has been developed to assess ND for the experimental program to determine the empirical and physical relationships between the ND results and the durability indicators of various concretes. The water and chloride gradient study program is, of course, critical to this effort in the maritime environment. The research techniques make use of non-destructive test methods for studying characteristics and compressive strength in hardened concrete. The mechanical properties of building materials were determined using destructive and non-destructive testing. Italian and European codes allow the use of some non-destructive test techniques, such as the Schmidt Hammer test, SonReb, and ultrasonic pulse velocity test, but always in combination with destructive testing. The in-situ strength of concrete was evaluated by means of non-destructive techniques after cylindrical specimens, or cores, were extracted from specific structural zones of the museum to obtain a more relevant correlation curve. Names, diameters, heights, and location on the structure of extracted cores were recorded. Among others, compressive strength, as well as related names of non-destructive tests carried out at structural points (UPV, Rebound) is mentioned.

Table 2 Cylinder Test Result for 28 Days

Sample No.	**Rebound Strength (Inclination Angle = 0°)**	**UPV (N/mm²)**
1	21.9	22.5
2	23.74	24.6
3	21.55	21.9
4	23.74	24.4
5	22.28	23.2
6	22.6	23.5
7	23.1	24.2
8	21.8	22.3
9	23.0	23.7
10	22.9	23.8
11	22.5	23.0
12	23.3	24.1
13	21.7	22.8
14	23.4	24.3
15	22.2	23.4
Avg.	22.68	23.53

Table 2 showing the Cylinder Test Result for 28 Days shows a comparison between Rebound Strength (measured at an inclination angle of 0°) and UPV (Ultrasonic Pulse Velocity) values across 15 samples. The average Rebound Strength value is 22.68, with a range of 21.7 to 23.74, suggesting a moderate variation among the samples. This suggests that the concrete's surface hardness remains consistent, with small fluctuations within an expected range. The UPV values range from 21.9 to 24.6 N/mm², with an average of 23.53. This is a good general quality of concrete. More UPV values mean denser and more compact concrete. The results of the Rebound Strength test show this. The tests show that although there is a small variation between the individual samples, the concrete samples perform consistently in both metrics. Average values of Rebound Strength were 22.68 and UPV, 23.53, respectively, suggesting the concrete's general satisfactory strength and density according to expectation for well-cured 28-day concrete.

Table 3 Core Test Result for 28 Days

Sample No.	Rebound Strength (Inclination Angle = 0°) (N/mm²)	UPV (N/mm²)
1	20.6	21.7
2	21.39	22.4
3	20.34	21.5
4	21.2	21.8

5	20.9	21.7
6	19.77	21.1
7	21.98	22.8
8	23.02	23.7
9	21.49	21.9
10	21.18	22.1
11	21.55	22.3
12	20.88	21.6
13	22.1	22.7
14	21.33	22.2
15	22.0	22.9
Avg.	21.20	22.10

Table 3 showing the Core Test Result for 28 Days gives an analysis of how Rebound Strength measured using an inclination angle of 0° relates to UPV (Ultrasonic Pulse Velocity) of 15 concrete samples. Average Rebound Strength is 21.20 N/mm² with range 19.77 and 23.02 N/mm², which indicates that the surface hardness of samples is constant (Fig. 3). UPV ranges from 21.1 to 23.7 N/mm², which averages at 22.10 N/mm²; hence, the concrete samples are generally of uniform quality and high density. The trend of results indicates that an increase in surface hardness has a tendency to improve internal concrete quality, such as density and strength, with UPV values. An average Rebound Strength of 21.20 N/mm² and UPV of 22.10 N/mm² shows that the concrete samples are well-cured and exhibit good structural integrity, with solid surface and internal strength after 28 days of curing.

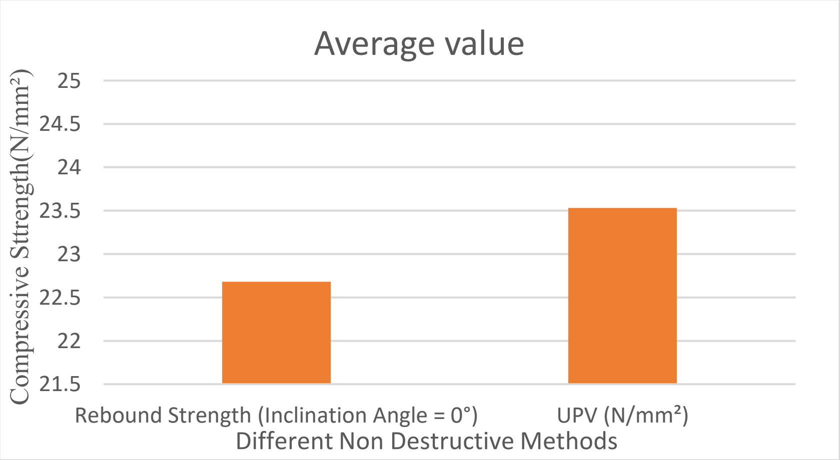

Fig. 3. Both non-destructive methods' compressive strengths in a cylindrical test

The average rebound strength and UPV for a batch of concrete specimens are illustrated in Fig. 4. The average UPV is 23.53 N/mm² and average Rebound Strength is 22.68 N/mm². After curing for 28 days, both values indicate that the concrete has good internal quality and surface hardness. The rebound strength measures the surface hardness, which reveals the overall durability and resistance to wear of the concrete. The higher the rebound number, the denser and stronger the surface is likely to be. Similarly, UPV is used to measure the internal properties of concrete, including its density and homogeneity, with higher values signifying better concrete quality and less porosity. In this case, the relatively close values of UPV and rebound strength suggest a close relationship between internal density of the concrete and surface hardness. This correspondence indicates that the concrete is not only hard on the surface but also has an uniform interior structure, which gives it the strength and endurance. The averages of 22.68 for rebound strength and 23.53 for UPV imply that the concrete is highly cured, and both external and internal characteristics meet standard requirements for long-term service.

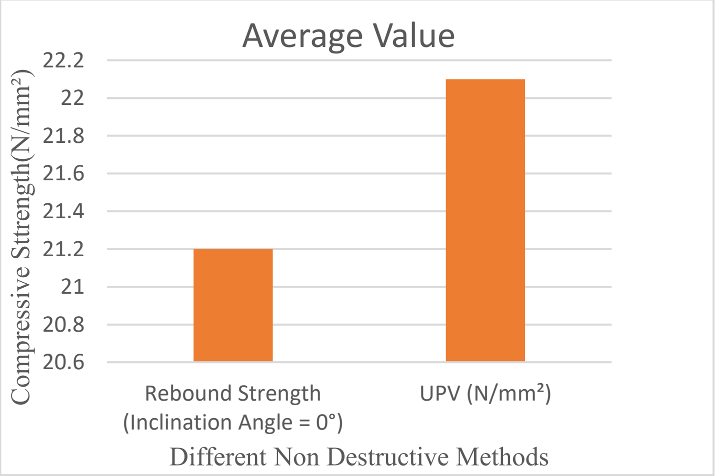

Fig. 4. Compressive strength in the core test using both non-destructive methods

The Core Test Results indicate the average values of rebound strength and ultrasonic pulse velocity (UPV) for the concrete samples. The average Rebound Strength is 21.20 N/mm², and the average UPV is 22.10 N/mm2. These results compare the surface hardness of the concrete with its internal quality. The rebound strength value of 21.20 N/mm2 shows that the surface of the concrete has a moderate level of strength and wear resistance, which is in accordance with its surface hardness. This is an important factor for durability because a higher rebound strength usually indicates a tougher surface layer. Meanwhile, the UPV at 22.10 N/mm² gives an internal condition of the concrete, as it shows relatively good density and uniformity within material. UPV measures a property of ultrasonic waves on traveling through the concrete. Higher the UPV value, then lower is the porosity and better quality in total. The fact that the Rebound Strength and UPV are closely aligned suggests the good correlation of the properties of the surface and internal qualities of the concrete. It shows a resilient surface but also gives a solid internal structure, though the results indicate possibilities to further optimize the mix for both surface and internal qualities, thus improving the final performance of the concrete in future tests.

5. Discussion

The results of this study underscore the significant influence of concrete mix design parameters - particularly aggregate absorption, specific gravity, and moisture content - on the correlation between non-destructive test (NDT) results and actual compressive strength. As observed, the close alignment between rebound hammer and ultrasonic pulse velocity (UPV) values for M20 grade concrete indicates a consistent internal structure and surface hardness, which is attributable to the controlled mix proportions and curing regime. This consistency supports the findings of Breysse [19], who emphasized that measurement quality in NDT-based strength estimation is highly dependent on material homogeneity and proper calibration. However, the slight but measurable variations in NDT responses across samples highlight the sensitivity of methods like rebound hammer and UPV to local material properties, a point also noted by Ali-Benyahia et al. [7] in their analysis of in-situ assessment accuracy. The integration of these two NDT methods provides a more robust in-situ evaluation framework, reducing reliance on extensive destructive testing while improving reliability, an approach aligned with the SonReb method validated by Pascale et al. [17] and Nobile [18]. For practical applications, especially in durability-critical environments such as marine exposures, these findings suggest that mix-specific calibration curves should be developed to account for aggregate characteristics and moisture conditions. This tailored approach can enhance the long-term monitoring and preservation of structural heritage, as emphasized by Balayssac and Garnier [12].

6. Conclusions

Evaluation of existing structures forms a major topic on which engineers and researchers are currently working. The on-site compressive strength of a reinforced concrete structure is essential for determining how safe it is. The importance of this study is that the it focuses on water and chloride gradients. These gradients are very vital in marine environments. This study assesses the properties and compressive strength of hardened concrete by using the test methods that are non-destructive. The present study investigates core compressive strength, cylinder compressive strength, rebound hammer, and ultrasonic pulse velocity of hardened concrete. Average Rebound Strength: 21.20 N/mm², reflecting moderate strength and wear resistance. Average Ultrasonic Pulse Velocity (UPV): 22.10 N/mm² in core compressive test indicating good density and uniformity.

- Average Rebound Strength: 22.68 N/mm², is indicating a denser, stronger surface. Average Ultrasonic Pulse Velocity (UPV): 23.53 N/mm² in cylindrical compressive strength, indicates better internal quality and less porosity Rebound Strength and UPV closely align, indicating well-correlated surface and internal properties.
- Results suggest potential for further optimization of mix for both surface and internal quality to improve concrete performance.
- Both values suggest a strong correlation between surface hardness and internal density, indicating a consistent internal structure. The concrete is well-cured, meeting expected standards for long-term performance.

References

1. A. Jain, A. Kathuria, A. Kumar, Y. Verma, K. Murari, Combined use of non-destructive tests for assessment of strength of concrete in structure. Procedia Eng. 54, 241–251 (2013)
2. J. Malek, M. Kaouther, Destructive and non-destructive testing of concrete structures. Jordan J. Civ. Eng. 8, 432–441 (2014)
3. C. Maierhofer, H.-W. Reinhardt, G. Dobmann (eds.), Non-destructive evaluation of reinforced concrete structures: non-destructive testing methods (Elsevier, 2010)
4. M. Rucka, Non-destructive testing of structures. Materials 13, 21 (2020)
5. V. Minutolo, S. Di Ronza, C. Eramo, R. Zona, The use of destructive and non-destructive testing in concrete strength assessment for a school building (2019)
6. J. Hoła, J. Bień, K. Schabowicz, Non-destructive and semi-destructive diagnostics of concrete structures in assessment of their durability. Bull. Pol. Acad. Sci. Tech. Sci. 63, 87–96 (2015)
7. K. Ali-Benyahia, S. Kenai, M. Ghrici, Z.-M. Sbartaï, S.-M. Elachachi, Analysis of the accuracy of in-situ concrete characteristic compressive strength assessment in real structures using destructive and non-destructive testing methods. Constr. Build. Mater. 366, 130161 (2023)
8. K. Schabowicz, Non-destructive testing of materials in civil engineering. Materials 12, 3237 (2019)
9. B. Wang, S. Zhong, T.-L. Lee, K.S. Fancey, J. Mi, Non-destructive testing and evaluation of composite materials/structures: a state-of-the-art review. Adv. Mech. Eng. 12, 1687814020913761 (2020)
10. A. Jain, A. Kathuria, A. Kumar, Y. Verma, K. Murari, Combined use of non-destructive tests for assessment of strength of concrete in structure. Procedia Eng. 54, 241–251 (2013)
11. I. Ivanchev, Investigation with non-destructive and destructive methods for assessment of concrete compressive strength. Appl. Sci. 12, 12172 (2022)
12. J.-P. Balayssac, V. Garnier (eds.), Non-destructive testing and evaluation of civil engineering structures (Elsevier, 2017)
13. G. Frappa, M. Miceli, M. Pauletta, Destructive and non-destructive tests on columns and cube specimens made with the same concrete mix. Constr. Build. Mater. 349, 128807 (2022)
14. G. Villain, A. Ihamouten, X. Dérobert, T. Sedran, O. Burban, O. Coffec, M. Dauvergne, J. Alexandre, L.M. Cottineau, M. Thiéry, Adapted mix design and characterization for non-destructive assessment of concrete, in Proc. MEDACHS (2010)
15. A. Thakur, R. Purohit, R. Rana, D. Bandhu, Characterization and evaluation of mechanical behavior of epoxy-CNT-bamboo matrix hybrid composites. Mater. Today Proc. 5, 3971–3980 (2018). https://doi.org/10.1016/j.matpr.2017.11.655
16. H. Erdal, M. Erdal, O. Simsek, H.I. Erdal, Prediction of concrete compressive strength using non-destructive test results. Comput. Concr. 21, 407–417 (2018)
17. G. Pascale, A. Di Leo, V. Bonora, Nondestructive assessment of the actual compressive strength of high-strength concrete. J. Mater. Civ. Eng. 15, 452–459 (2003)
18. L. Nobile, Prediction of concrete compressive strength by combined non-destructive methods. Meccanica 50, 411–417 (2015)
19. M. Ju, K. Park, H. Oh, Estimation of compressive strength of high strength concrete using non-destructive technique and concrete core strength. Appl. Sci. 7, 1249 (2017)
20. J.A. Bogas, M.G. Gomes, A. Gomes, Compressive strength evaluation of structural lightweight concrete by non-destructive ultrasonic pulse velocity method. Ultrasonics 53, 962–972 (2013)
21. G.P. Yadav, D. Bandhu, S. Chatterjee, P.K. Gangwar, Optimizing diesel engine performance and emissions with mahua biodiesel blends using Taguchi methodology. PLoS One 20, e0332035 (2025)
22. Ş. Karahan, A. Büyüksaraç, E. Işık, The relationship between concrete strengths obtained by destructive and non-destructive methods. Iran. J. Sci. Technol. Trans. Civ. Eng. 44, 91–105 (2020).