Journal of Engineering Science 15(1), 2024, 1-10
DOI: https://doi.org/10.3329/jes.v15i1.76000

JES
an international Journal

ASSESSMENT OF COMPRESSIVE STRENGTH OF CONCRETE USING THE CAPO TEST

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Received: 06 December 2023 Accepted: 22 June 2024

ABSTRACT

The CAPO-Test or the Cut and Pull-Out test, also known as the pull-out test, is gaining popularity as a method for estimating the compressive strength of existing concrete structures due to its reliability, less structural damage compared to core collection, and quick in-place strength. The manufacturer of the pull-out machine has provided a general correlation for assessing the in-place concrete strength of stone chip-based concrete. Many of the concrete buildings in Bangladesh are made of brick chip-based concrete. In a few projects in Bangladesh, the CAPO test has been used to assess the concrete strength of existing structures. However, the reliability of this test for concrete made of brick chips has yet to be investigated. 20 columns from five distinct structures, which varied in age from 14 to 45 years at the time of testing, underwent the CAPO and core tests for this study. Based on the fundamental findings of this investigation, a general correlation has been established regarding concrete composed of brick chips. According to the findings, the CAPO-Test f or concrete with brick chips shows estimated strengths using the proposed correlation varies between 0% and 30% of the core strength. No prior research has been identified on evaluating the concrete strength of existing structures containing brick chips using the CAPO test; therefore, this study supports the CAPO-Test's reliability in conducting in-situ concrete strength assessments of brick chip-based structures.

Keywords: *CAPO-Test, Pull-out test, Compressive strength, Correlation, Brick chips, Structural assessment*

1. INTRODUCTION

The assessment of the concrete compressive strength is one of the most important aspects to consider when determining the overall load-carrying capability of existing reinforced concrete structures. Destructive testing of the concrete core collection is a common method to evaluate the in-place compressive strength of concrete. Besides many advantages of core tests, core collection may create difficulties for the presence of steel in concrete members, also this process leaves holes in the structure and the total process from core collection to preparation and testing is costly and time-consuming as well. Instead of using drilled cores to measure the compressive strength of the concrete in place, a pull-out test with post-installed inserts has been investigated (Thun et al., 2009; Petersen, 2022).

Some in-situ techniques are entirely non-destructive, while others are only partially so since they cause surface damage, but far less severe than that caused by drilling core. Rebound hammer, ultrasonic pulse velocity measurement, and resonant frequency test are examples of non-destructive methods for determining in-place compressive strength. On the other hand, the CAPO-TEST, lok test, friction transfer test, break-off, and penetration resistance test demonstrate partially destructive methods. Since these partially destructive methods may inflict minimal damage and have no impact on the structural integrity, they are commonly referred to as Non-Destructive Tests (NDTs) in many different circumstances (Sourav et al., 2019; Al-Sabah et al., 2021; Pannuzzo et al., 2023).

Despite their limitation to the exterior concrete layer of structures, CAPO-TEST tests have been demonstrated to be a dependable method for the in-situ assessment of concrete strength (Brencich, 2015, Pannuzzo et al., 2023; Ullah et al., 2024). Among the several non-destructive tests that can be employed, it is widely acknowledged that CAPO Test provides the greatest potential for being accepted as a reliable indicator of determining the in-place compressive strength of concrete (Sayed 1987). Although pull-out tests were first developed in the Soviet Union in the late 1930s and early 1940s (Skramtajew, 1938; Tremper, 1944), the relatively recent pull-out (CAPO) techniques are specifically made for in-situ concrete testing and, in contrast to most non-destructive methods, have the benefit of direct assessment of some strength parameters.

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ISSN 2075-4914 (print); ISSN 2706-6835 (online)

Several researchers (Krenchel and Petersen, 1984; Nasser and Al-Manaseer, 1987; Moczko et al. 2016; Brencich 2015 and Pannuzzo et al. 2023) have established an empirical relationship between the CAPO test and the compressive strength of concrete specimens, including cylinders, cubes, or cores, composed of stone chips. In this study, a total of twenty tests were conducted, out of which the results of four tests showed significant deviation. The remaining sixteen test results were used for comparison and correlation development. The difference between the core test results and those estimated from the proposed CAPO force and concrete strength correlation ranged from 1% to 30%, indicating a notable discrepancy that should not be used in practical evaluation. With no established correlation using the CAPO test for assessing concrete strength with brick chips for existing structures, this study highlights the challenge of reliably assessing concrete strength in such compositions. It also proposes an empirical linear relationship where the regression value (R) is 0.94 and a non-linear relationship between CAPO pull-out force and the compressive strength of concrete cores.

2. MATERIALS AND METHODS

The CAPO-TEST is an indirect method that necessitates the utilization of an empirical correlation to determine the in-place compressive strength of concrete based on the parameter recorded by the test method (Moczko et al. 2016). The CAPO test has been observed to have a significant correlation with compressive strength; nevertheless, it is important to note that concrete is subjected to a variety of stresses (Al-Sasbah et al. 2021). The state of stresses in the pull-out test is difficult to analyse, and the level of strength achieved in this test suggests that it may evaluate the direct shear strength of concrete (Malhotra and Carette, 1980). Applying Coulomb's criterion for sliding failure demonstrated a direct proportionality between the pull-out force and the concrete compressive strength (Jensen and Braestrup, 1976).

2.1 CAPO-TEST mechanism

The CAPO-TEST device is used to obtain an acceptable approximation of the in-situ compressive strength of concrete on existing buildings by using a post-installed pullout test that meets the ASTM C900-15 (2015) and EN 12504-3 (2005) requirements. The phrase "post-installed" refers to the characteristic of CAPO-TEST wherein it does not necessitate the prior placement of inserts in newly poured concrete. The ASTM C900-15 standard provides a prescribed set of steps for conducting a post-installed pullout test, as illustrated in Figure 1. The examination can be conducted on an already existing construction situated in any accessible area.

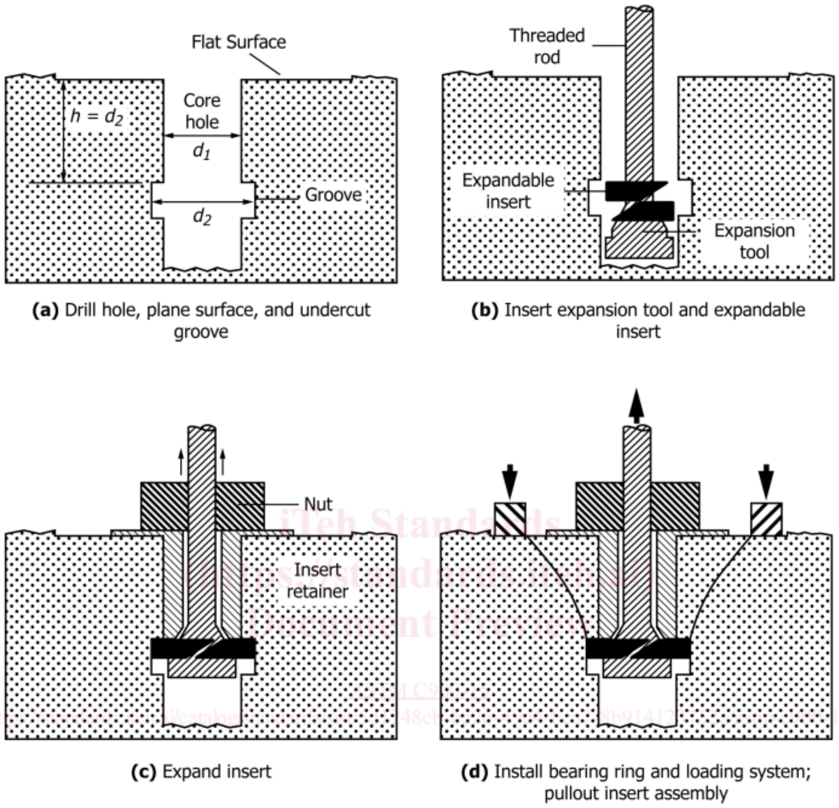
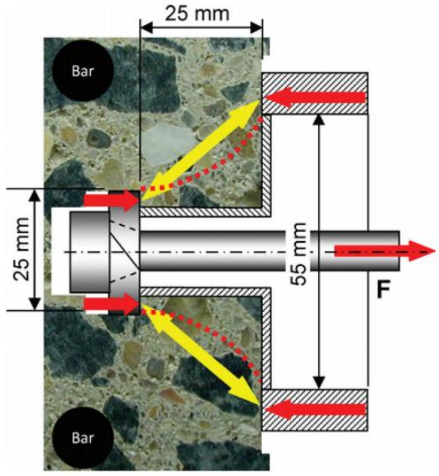


Figure 1: Schematic of Procedure for Post-Installed Pullout Test (after ASTM C900-15 2015)

2.2 Failure Mechanism

The CAPO-TEST (Pull-out test) involves the use of a ring that is enlarged within a recessed area with an undercut in an existing concrete structure (Petersen 1980). The pullout process involves the application of counterpressure, as demonstrated in Figure 1a, which results in the generation of compression forces between the expanding ring and the counterpressure. Consequently, the pullout force serves as a direct indicator of the compressive strength. The failure in this mechanism is attributed to the crushing of the concrete within the "strut" connecting the disc and the counterpressure (Ottosen 1981).



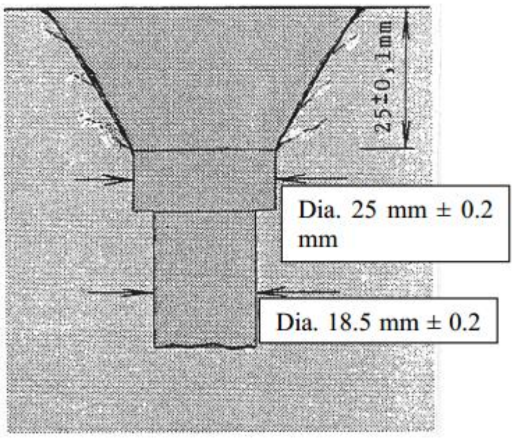


Figure 2: (a) Cross-sectional view of CAPO-TEST (b) Cross-section of Capo-Test failure with minor circumferential cracking (after Germann Instruments, Manual 2018)

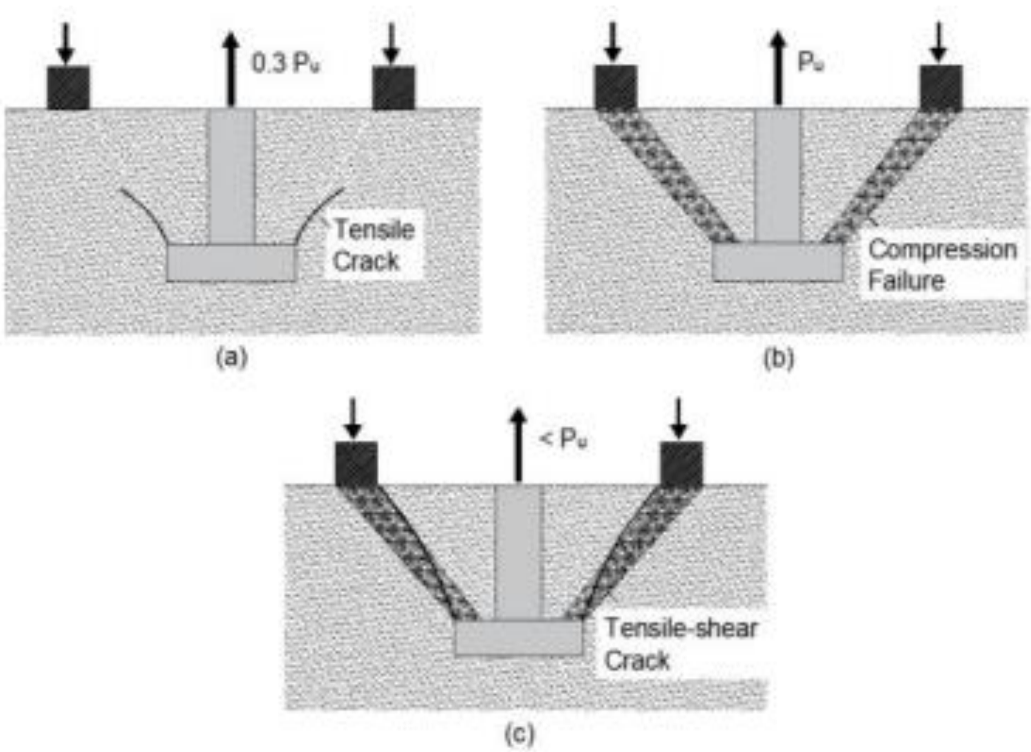


Figure 3: Failure sequence of pull-out tests (after Pannuzzo et al., 2023)

Figure 2b depicts the cross-sectional view of the Capo-Test failure, showcasing the presence of slight circumferential cracking, and Figure 3 demonstrates the sequence of failure during the pull-out test. Although there is a strong association between pull-out and concrete's compressive strength, there is no complete consensus on uniaxial compressive failure. Because of this, a direct empirical relationship must be constructed for each specific concrete and testing device.

2.3 CAPO-Test correlations

Generally, the testing equipment manufacturer gives a graph or equation showing the relationship between compressive strength of concrete and pull-out force. The CAPO-TEST equipment manufactured by Germann Instruments A/S was used in this study. The manufacturer supplied the correlation established by Moczko et al. (2016) for the purpose of evaluating concrete strength using their equipment. In addition, there are other sources (Petersen and Poulsen 1993; Krenchel and Petersen 1984; CSA A23.1-14/A23.2-14 2014 and ACI Committee 228 2003) that discuss different methodologies for establishing a correlation between the results of the CAPO-TEST and the compressive strength of standard specimens.

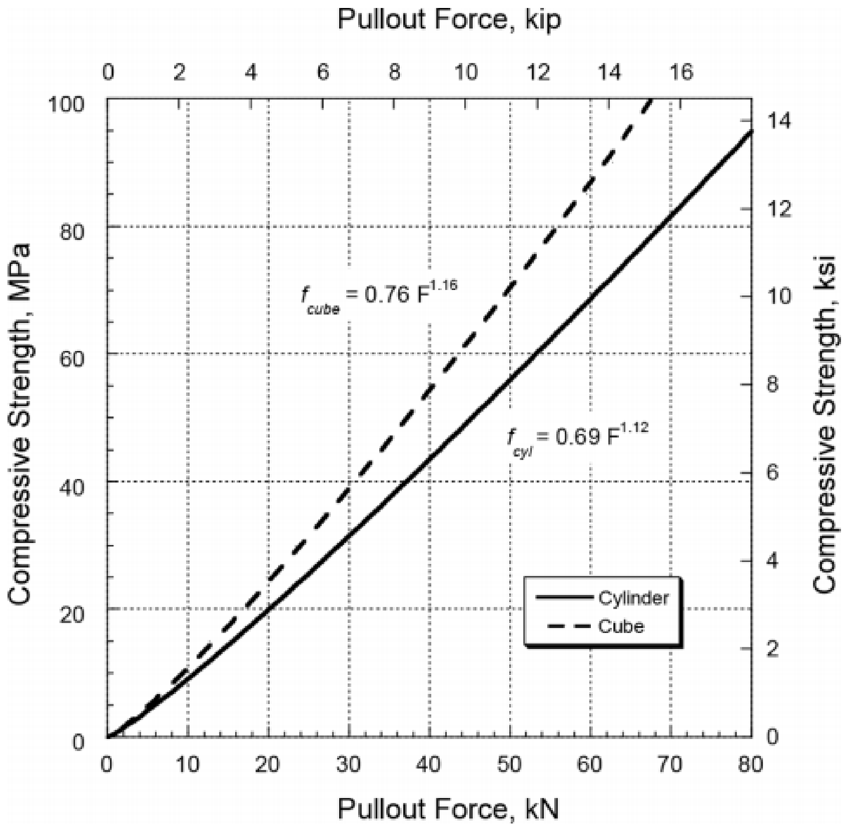


Figure 4: CAPO-TEST general correlations for evaluating compressive strength based on pullout testing (after Malhotra and Carino, 2003)

Moczko et al. (2016) demonstrated that the general correlation between the pull-out force (F) and the 150 mm (6 in.) cube strength, fcube = 0.76F1.16, and the 100 mm diameter to 100 mm depth core strengths obtained from bridges, is within the confidence limits of the correlation. Hence, the compressive strength of cores measuring 100 x 100 mm (4 x 4 in.) is comparable to that of cubes measuring 150 mm (6 in.). The general correlations for determining the compressive strength of cylinders or cubes based on pullout tests are compiled by Malhotra and Carino (2003) shown in Figure 4. Previous research (Krenchel and Petersen 1984 and Petersen 1997) has demonstrated that the aforementioned overall associations remain consistent regardless of the specific cementitious materials employed, the ratio of the water-cementitious material (w/cm), the level of maturity, the utilization of self-consolidating concrete, the inclusion of fibers, the presence of air entrainment, the incorporation of admixtures, the conditions under which curing takes place, the stresses experienced by the structure, the rigidity of the member, and the characteristics about the shape, type, and size of aggregate up to a maximum diameter of 40 mm (1.6 in.).

3. DATA COLLECTION

For this investigation, five buildings of varying ages were chosen (Table 1). The structures range in age from 14 to 45 years, and the concrete elements are formed of brick chip aggregate. Data was taken from roughly the same place of the column in a few days' intervals. Figure 5 shows the pullout CAPO-TEST and the core sample collections at the same location from a column of Avoy Binodini High School. A total of 20 core samples were obtained from chosen columns of the buildings and delivered to the laboratory for determining the compressive strength of the core samples. A CAPO-TEST was also performed at the same location of every column from which a core sample had been collected.

Figure 5: The CAPO-TEST (top row images) and core collection (Bottom row images) from a column

4. PREPARATION AND TESTING OF CONCRETE CORES

Cores were recovered using a HILTI DD200 core rig with an attached vacuum rig. Core specimens with a diameter of 3 inches (75 mm) and a height of 6 inches (150 mm) were prepared for compressive strength testing.

Table 1: Test result of pullout force, CAPO strength, and core strength

Sl No	Facility Name	Construction Year	Element	Pull out Force (kN)	Core Strength (MPa)
1	Bashabo Girls School	1978	Column	12	7.8
2			Column	8.3	14.4
3			Column	13.6	14.3
4	Avoy Binodini High School	1982	Column	8.3	8.8
5			Column	6.5	8.6
6			Column	3.7	7.2
7			Column	9.1	11.2
8	BPATC College	2000	Column	8.6	6.8
9			Column	5.6	7.8
10	BPATC College-2	1990	Column	30	30.8
11			Column	25	30.7
12	Rajarbag Primary school	1999	Column	29.1	25.9
13			Column	10.2	10.5
14			Column	15.8	16.7

Sl No	Facility Name	Construction Year	Element	Pull out Force (kN)	Core Strength (MPa)
15	Chapain New Model High School	2009	Column	15.3	15.5
16			Column	13.1	15.8
17			Column	21	23.6
18			Column	4.2	5.9
19			Column	15.8	16.8
20			Column	7.2	6.1

*Correlation suggested by Malhotra and Carino (2003)

The specimens were capped and tested in the laboratory. If the ends of the cores did not meet the perpendicularity and planeness requirements of Test Method C39/C39M-15a, they were sawed or ground to meet those requirements or capped according to Practice ASTM C617/C617M-15. When using Practice C617 for capping, the device accommodated the actual core diameters and produced concentric caps with the core ends (ASTM C42-12). The cores were tested one or two days after coring. The load was applied perpendicular to the surface of the core continuously and without shock, as illustrated in Figure 6. The failure load was recorded.

Figure 6: (a) Measure the core sample and (b) Testing of Cores

5. COMPARISON BETWEEN SUGGESTED AND MANUFACTURER'S CORRELATION

Upon analyzing the test findings, it has been proposed that there exists a correlation between pullout force recorded in instruments and core strength, as depicted in Figure 6. Additionally, it demonstrates that the relationship presents a minor nonlinearity. The study notably emphasizes a disparity between the correlation observed in the current examination for concrete made from brick chips and the correlation supplied by the manufacturer for concrete made from stone chips. These findings suggest that the correlation between pullout force and core strength can differ based on the composition of the concrete under examination.

Table 2 shows that there is major difference of results for four locations which are more than 40 percent. Ignoring those four results rests of the estimated strength by the CAPO-Test using the manufacturer correlation is approximately 1 ~ 36% greater than the measured core strength and there is a linear co-relation developed as depicted in Figure 7.

Table 2: Relative differences of compressive strength of concrete Based on CAPO and Core test

Sl No	Facility Name	Construction Year	Element	Pull out Force (kN)	CAPO-TEST Strength using Manufacturer correlation*, MPa	Core Strength, MPa	Difference Core to CAPO test (%)
1	Bashabo Girls School	1978	Column	12	13.57	7.8	-74%
2			Column	8.3	8.85	14.4	39%
3			Column	13.6	15.69	14.3	-10%
4		1982	Column	8.3	8.85	8.8	-1%

Sl No	Facility Name	Construction Year	Element	Pull out Force (kN)	CAPO-TEST Strength using Manufacturer correlation*, MPa	Core Strength, MPa	Difference Core to CAPO test (%)
5	Avoy Binodini High School		Column	6.5	6.66	8.6	23%
6			Column	3.7	3.47	7.2	52%
7			Column	9.1	9.85	11.2	12%
8	BPATC College	2000	Column	8.6	9.22	6.8	-36%
9			Column	5.6	5.61	7.8	28%
10	BPATC College-2	1990	Column	30	39.29	30.8	-28%
11			Column	25	31.80	30.7	-4%
12	Rajarbag Primary school	1999	Column	29.1	37.93	25.9	-46%
13			Column	10.2	11.24	10.5	-7%
14			Column	15.8	18.67	16.7	-12%
15	Chapain New Model High School	2009	Column	15.3	17.99	15.5	-16%
16			Column	13.1	15.03	15.8	5%
17			Column	21	25.98	23.6	-10%
18			Column	4.2	4.02	5.9	32%
19			Column	15.8	18.67	16.8	-11%
20			Column	7.2	7.50	6.1	-23%

*Correlation suggested by Malhotra and Carino (2003)

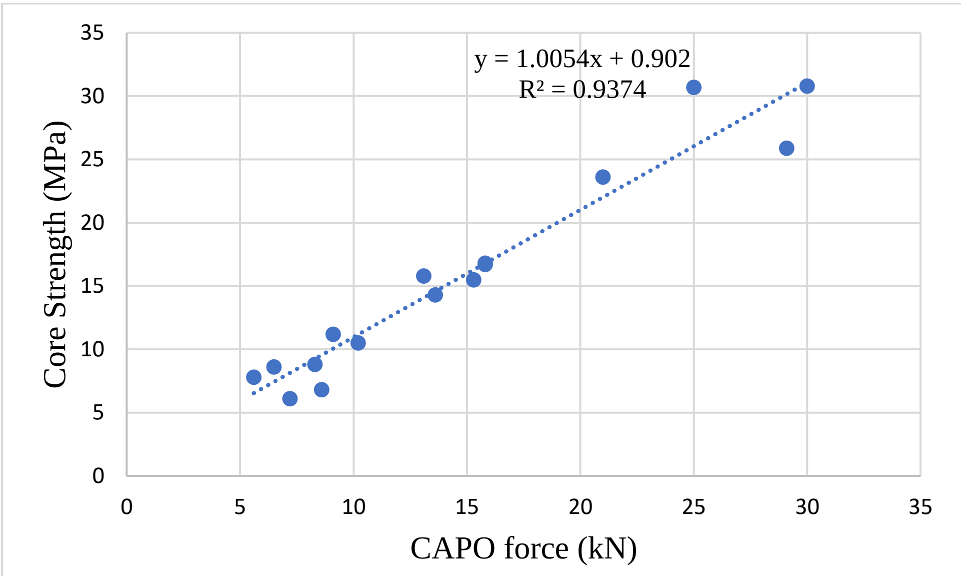


Figure 7: Correlation between CAPO Force and Core Compressive Strength for Concrete of Existing Building made from brick Chips

Figure 7 illustrates that the linear relationship between concrete core strength and CAPO pullout force is more consistent at lower strength levels up to 20 MPa. In contrast, data points become more scattered beyond 20 MPa. The linear correlation between core strength (f_{core}) and pullout force (F) can be expressed as follows:

$$f_{core}=1.0054F+0.902 \quad (1)$$

where f_{core} represents the core compressive strength in MPa, and F denotes the pullout force in kN. This relationship is characterized by a regression coefficient (R^2) of 0.9374, indicating a strong and acceptable correlation between the measured variables especially when strength is under 20 Mpa.

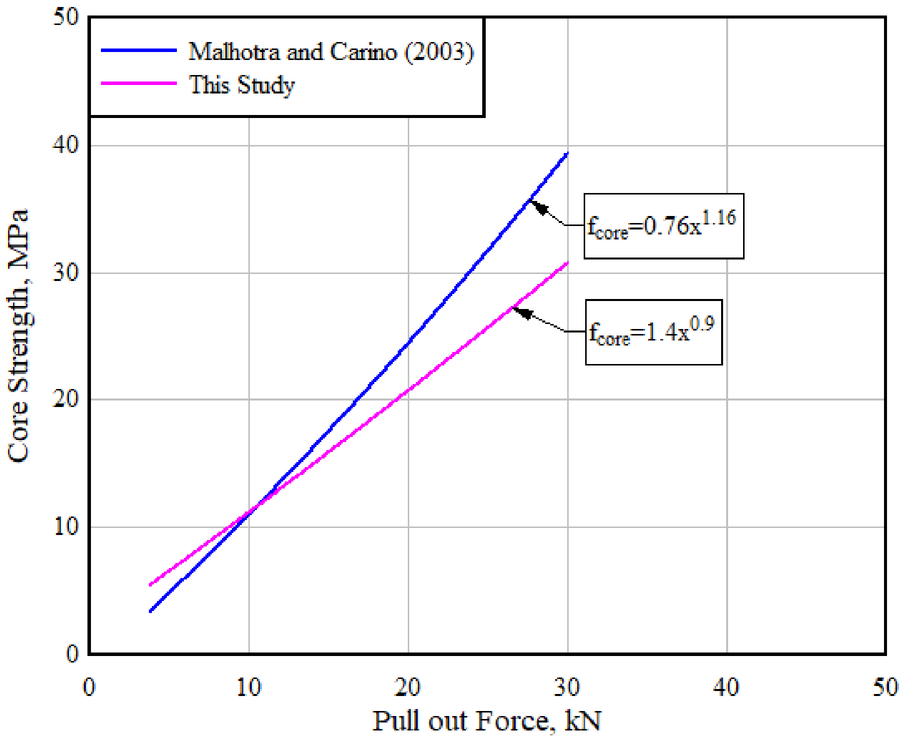


Figure 8: Comparing general correlations using CAPO-TEST to estimate compressive strength based on pullout testing

Figure 8 illustrates the overall relationship between CAPO-TEST results and estimated compressive strength derived from pullout testing, comparing the findings from this study with the manufacturer-suggested correlation (Malhotra and Carino, 2003). The figure indicates a notable difference between the two relationships. Specifically, the strength values in this study are higher up to approximately 12 MPa, after which the curve declines relative to the established correlation by Malhotra and Carino (2003). This suggests that the graph from this study has a gentler slope compared to the manufacturer-suggested correlation. Equation (2) is selected as the appropriate curve for this study, accurately depicting the correlation between core compressive strength (f_{core}) and pullout force (F) is as follows:

$$f_{\text{core strength}} = 1.4F^{0.9} \qquad (2)$$

where f_{core} is the core compressive strength, in MPa; and F is the pullout force, in kN.

This equation presents a precise mathematical representation of the connection between the force required to take something out and the strength of the core, which is specific to the composition of concrete under investigation. This method captures the observed relationship between variables and enables the estimate of the fundamental compressive strength by using pullout force measurements.

Table 3 shows that the range of variation of results from the proposed correlation from this study to estimated concrete core strength is 0% to 30%. This variation could potentially be minimized by conducting more extensive testing with a larger dataset, which can be considered a limitation of this study.

Table 3: Summary of compressive strength of concrete based on core strength with correlation proposed in this study

Sl No	Facility Name	Construction Year	Element	Pull out Force (kN)	Core Strength (MPa)	CAPO-Test Strength using Proposed correlation (MPa)	Difference Core to CAPO Test (%)
1	Bashabo Girls School		Column	13.6	14.3	14.7	-2%
2	Avoy Binodini High School	1982	Column	8.3	8.8	9.4	-6%
3			Column	6.5	8.6	7.5	14%
4			Column	9.1	11.2	10.2	10%
5	BPATC College	2000	Column	8.6	6.8	9.7	-30%
6			Column	5.6	7.8	6.6	18%
7	BPATC College-2	1990	Column	30	30.8	29.9	3%
8			Column	25	30.7	25.4	21%
9	Rajarbag Primary school	1999	Column	29.1	25.9	11.3	-7%
10			Column	10.2	10.5	16.8	-1%
11			Column	15.8	16.7	16.3	-5%
12	Chapain New Model High School	2009	Column	15.3	15.5	14.2	11%
13			Column	13.1	15.8	21.7	9%
14			Column	21	23.6	29.1	-11%
15			Column	15.8	16.8	16.8	0%
16			Column	7.2	6.1	8.3	-26%

6. CONCLUSIONS

The objective of this study was to evaluate the applicability of the manufacturer's correlation (Malhotra and Carino, 2003), which was originally established for concrete made with stone chips, in assessing the strength of concrete composed of brick chips. Additionally, this study aimed to establish a new correlation between the pullout force and concrete's compressive strength, specifically when brick chips are used as the coarse aggregate. Despite an extensive literature review, no existing studies were found that establish a correlation between CAPO-TEST results and the compressive strength of concrete made with brick chips in assessing existing structures. Therefore, this study seeks to provide insights into how the relationship might differ when brick chips are used in the concrete mix.

The variation between the results from the proposed correlation and the concrete core strength ranges from 0% to 30%. When compared to the manufacturer-suggested correlation (Malhotra and Carino, 2003) for the CAPO machine, the graph of the proposed correlation, which is based on brick chip concrete, is milder than that suggested for stone chip concrete. Due to the limited test results in this higher strength range, the proposed relationship may deviate from actual conditions.

Hence, it is imperative to exercise caution when applying the findings of this study to practical applications in the field, particularly in the assessment of concrete strength derived from brick chips. A comprehensive investigation that includes diverse factors such as concrete grade variations, more datasets is all ranges of concrete grade, and aged concrete conditions is necessary to establish a more reliable understanding of this relationship.

ACKNOWLEDGMENTS

The author expresses gratitude to the Project Director of the Urban Resilience Project: RAJUK Part for the instrumental support to carry out the study.

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