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Correlation Between Rebound-Hammer Compressive Strength and Surface Resistivity of Concrete at Different Curing Ages

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ABSTRACT *: Compressive strength and resistance to chloride ingress largely determine whether a concrete element performs throughout its service life, yet both are traditionally assessed by slow, sample-consuming procedures. This study examines how two non-destructive indicators, rebound-hammer compressive strength and four-point Wenner surface resistivity, develop with curing age and how closely they correlate. Two mixes, M10 (1:3:6) and M15 (1:2:4), were produced at a constant water-to-cement ratio of 0.5, and eighteen 150 mm cubes were tested at 7, 14 and 28 days in accordance with ASTM C805 and AASHTO T358. Compressive strength rose from 6.21 to 9.94 N/mm² (M10) and from 9.01 to 15.02 N/mm² (M15), while surface resistivity increased from 5.36 to 13.08 kΩ·cm and from 7.41 to 18.52 kΩ·cm, respectively. One-way analysis of variance confirmed that curing age significantly affected both properties ($p < 0.05$). Both mixes migrated from the "high" toward the "moderate" chloride-penetrability band of AASHTO T358, although neither reached the "low" class by 28 days. A significant linear relationship, $f_c = 0.611\rho + 3.456$ ($r = 0.933$, $R^2 = 0.870$, $p < 0.01$), predicted strength from resistivity with a mean error below 10%, and grade-specific models fitted more tightly ($R^2 \geq 0.98$). Resistivity readings were far more repeatable than rebound readings, with coefficients of variation of about 5-9% against 18 to 25% of rebound hammer readings. The findings support the combined use of both techniques for rapid, simultaneous screening of strength and durability, while cautioning that rebound estimates at low strengths remain indicative.*

KEYWORDS: *Non-destructive testing, rebound hammer, surface resistivity, compressive strength, chloride ion penetration, curing age*

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I. INTRODUCTION

Concrete remains the most widely used construction material because of its versatility, relatively low cost, and reliable compressive strength (Mehta & Monteiro, 2014). However, the long-term performance of concrete depends not only on its strength but also on its durability. One of the most important durability concerns is resistance to chloride penetration, as chlorides can reach the reinforcing steel, degrade its protective layer, and initiate corrosion (Angst et al., 2009; Shi et al., 2012). Consequently, a concrete element may achieve the required compressive strength but still deteriorate prematurely if it allows excessive chloride ingress.Although extensive studies have investigated rebound hammer testing and surface resistivity separately, relatively few studies have examined both techniques on the same concrete specimens over different curing ages. This gap is important because a reliable relationship between strength and chloride penetrability obtained from a single inspection could significantly improve quality control and reduce the time required for condition assessment. Therefore, this study aims to: (i) estimate the compressive strength of M10 and M15 concrete using the rebound hammer at 7, 14, and 28 days; (ii) determine the surface resistivity of the concrete at the same curing ages and classify the corresponding chloride penetration resistance; and (iii) establish and model the relationship between rebound hammer strength and surface resistivity across different concrete grades and curing periods. The study is limited to laboratory-cured concrete cubes of two mix grades, produced at a single water-cement ratio, and tested for up to 28 days. Field conditions, longer curing periods, and other non-destructive testing methods are beyond the scope of the investigation.

The study makes three important contributions. First, it evaluates rebound hammer and surface resistivity on the same concrete specimens and monitors their development throughout the curing period rather than at a single testing age. Second, it establishes both general and grade-specific relationships between the two parameters, including measures of prediction accuracy and uncertainty, thereby improving the reliability of the proposed models. Third, it compares the repeatability of rebound hammer and surface resistivity measurements, providing engineers and quality-control personnel with practical guidance on the relative usefulness of each method for assessing concrete quality and durability.

II. BACKGROUND AND RELATED WORKS

The rebound hammer remains the most widely deployed surface-hardness tool, valued for speed and simplicity but repeatedly shown to be context-dependent. Chen et al. (2023) calibrated rebound readings against high-strength concrete in the Xinjiang region and confirmed that region and mix-specific calibration is necessary if the estimate is to be trusted. Revilla-Cuesta et al. (2022) found that standard rebound correlations systematically mis-predicted the strength of recycled-aggregate self-compacting concrete because its surface hardness differs from that of conventional concrete, while Mengistu et al. (2023) demonstrated on historical clay brickwork that the chosen test location alone can shift the apparent strength. Celerinos et al. (2023) added that seawater exposure perturbs rebound numbers and, therefore, the inferred strength. The recurring finding in the literature is that the rebound hammer is a useful and practical tool for preliminary concrete assessment. However, its accuracy depends largely on proper calibration and the condition of the concrete surface. Factors such as surface roughness, moisture content, curing age, and concrete composition can significantly influence the measured rebound values. These limitations become more pronounced at early curing ages and in non-standard concrete mixtures, where the relationship between rebound number and actual compressive strength may be less reliable. Consequently, the rebound hammer should be used as a screening or quality-control tool, with its results interpreted alongside appropriate calibration relationships and, where necessary, supplementary tests.

Chloride enters concrete by diffusion, permeation and capillary absorption, all governed by the connectivity of the pore structure (Shi et al., 2012). Amadi et al. (2022) showed that weaker recycled aggregates accelerate chloride penetration, though appropriate curing partly offsets the effect, and Kim (2022) reported that industrial-byproduct admixtures alter chloride resistance to differing degrees. Surface resistivity has emerged as a convenient proxy for this transport behaviour. Pablo-Calderon et al. (2023) related the resistivity of fly-ash-blended mortars to reduced chloride penetration, and Aragoncillo and Lomboy (2022) found that resistivity correlated strongly with both chloride diffusivity and water permeability in recycled-aggregate concrete. Robles et al. (2022) cautioned, in a wide-ranging review, that resistivity is sensitive to moisture state, temperature and curing, so standardised procedures are essential. AASHTO T358 codifies the interpretation by mapping resistivity to qualitative chloride-penetrability classes, which provide the durability scale used in the present study.

Evidence on the strength-durability link is consistent in direction but variable in strength. Kim et al. (2025) observed that as low-carbon concretes gained strength with age, their electrical resistivity and chloride-migration resistance increased in step, while Castillo and Hedjazi (2024) built empirical models in which resistivity estimated the early-age strength of fibre-reinforced concrete, the accuracy depending on mix and moisture. In contrast, Revilla-Cuesta et al. (2022) and Celerinos et al. (2023) showed that the relationship can break down under non-standard materials or aggressive exposure conditions. Earlier work tied the same threads to microstructure: Gowers and Millard (1999) and Layssi et al. (2015) established resistivity as a corrosion- and durability-relevant measurement, Hornbostel et al. (2013) reviewed its link to corrosion rate, Andrade (1993) connected ionic migration to chloride diffusion, and Lian et al. (2011) related porosity directly to strength. The balance of evidence justifies expecting a positive strength-resistivity correlation under controlled curing, while warning that it is neither universal nor a substitute for direct durability measurement.

III. MATERIALS AND METHODS

3.1 Materials and Mix Proportions

Portland limestone cement was used as the binding material in this study. River sand and crushed granite served as the fine and coarse aggregates, respectively, while potable water free from visible impurities was used for both mixing and curing. Two concrete grades, M10 and M15, were produced using mix proportions of 1:3:6 and 1:2:4, respectively, by mass. A constant water-to-cement ratio of 0.5 was maintained for both mixes to ensure that any observed differences in strength and durability characteristics could be attributed to variations in mix proportions rather than to changes in water content. The details of the mix proportions are presented in Table 1.

Table 1: Mix proportions adopted in the study

Mix	Nominal ratio (C:FA:CA)	Water/cement ratio	Cubes cast
M10	1 : 3 : 6	0.50	9
M15	1 : 2 : 4	0.50	9

3.2 Specimen Preparation and Curing

Concrete was batched by mass to the proportions above. Fresh concrete was placed in oiled 150 × 150 × 150 mm steel moulds in three layers, each rodded with a standard tamping bar to expel entrapped air. A total of 18 cubes were produced, 3 per mix and testing age, covering the 7, 14, and 28-day ages for both M10 and M15. Specimens were demoulded 24 hours after casting and immersed in a clean-water curing tank until the designated test age, after which they were surface-dried before testing.

3.3 Rebound Hammer Test (ASTM C805)

Compressive strength was estimated with a Proceq Original Schmidt Type-N rebound hammer in accordance with ASTM C805. Surfaces were wiped free of surface moisture before testing. With the plunger held vertically downward and normal to the cube face, nine readings were taken across each specimen, avoiding edges and corners. The nine readings were averaged to a representative rebound number for each cube, and the manufacturer's calibration chart was used to convert the average rebound number into an equivalent compressive strength. The coefficient of variation of the nine readings was retained as a measure of within-specimen scatter.

3.4 Surface Resistivity Test (AASHTO T358)

Surface resistivity was measured with a four-point Wenner probe meter (ProceqResipod) in accordance with AASHTO T358, using a 38 mm electrode spacing. Three equidistant measurement lines were taken across the mid-face of each cube and averaged; the resulting value is reported in kΩ·cm. Each resistivity value was then assigned to a chloride-penetrability class using the AASHTO T358 scale reproduced in Table 2.

Table 2: AASHTO T358 chloride-ion penetrability classes by surface resistivity

Surface resistivity (kΩ·cm)	Chloride-ion penetrability
< 12	High
12 – 21	Moderate
21 – 37	Low
37 – 254	Very low
> 254	Negligible

3.5 Data Analysis

For each mix and age, the mean rebound number, the mean resistivity and their coefficients of variation were computed. The relationship between compressive strength and surface resistivity was examined by ordinary least-squares linear regression, both pooled across all six mix-age groups and separately for each grade. The Pearson correlation coefficient (r), coefficient of determination (R^2), regression slope with its standard error, and the significance level (p) were used to characterise the fit.

IV. RESULTS AND DISCUSSION

4.1 Compressive Strength Development

Table 3 summarises the mean rebound number, within-specimen coefficient of variation and the estimated compressive strength for each mix and age. Strength increased monotonically with curing age for both mixes. For M10, it rose from 6.21 N/mm² at 7 days to 8.02 N/mm² at 14 days (a 29.1% gain) and 9.94 N/mm² at 28 days (a further 23.9%), an overall increase of about 60% between 7 and 28 days. M15 advanced from 9.01 to 11.81 N/mm² (31.1%) and then to 15.02 N/mm² (27.2%), for an overall gain of nearly 67%. At every age, M15 was the stronger mix, by roughly 45–51%, and its 28-day strength sat close to its nominal 15 N/mm² grade. The trend, shown in Fig. 1, is consistent with progressive hydration and the accumulation of calcium-silicate-hydrate gel that stiffens and strengthens the matrix over time (Neville, 2011).

Table 3: Rebound number, scatter and estimated compressive strength

Mix	Age (days)	Mean rebound no.	CoV of readings (%)	Est. compressive strength (N/mm²)
M10	7	13.15	18.1	6.21
M10	14	14.44	27.0	8.02
M10	28	15.81	26.9	9.94
M15	7	15.26	24.4	9.01
M15	14	17.15	21.0	11.81
M15	28	19.44	28.0	15.02

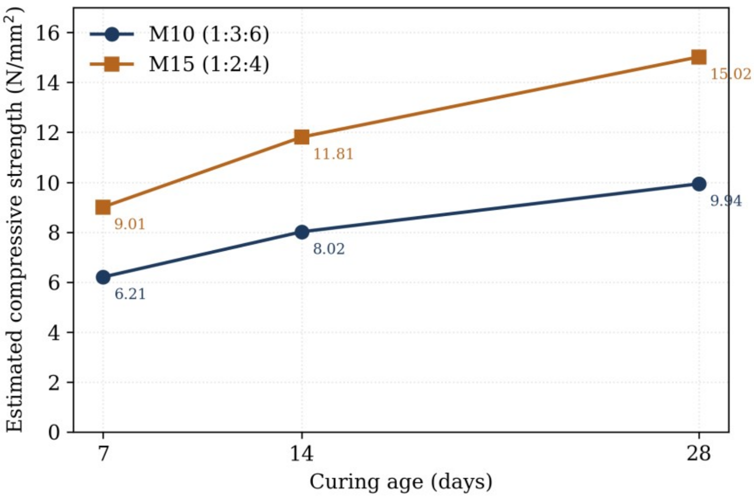

Fig. 1: Estimated compressive strength against curing age for M10 and M15

The coefficients of variation of the rebound readings, ranging from approximately 18% to 28%, warrant careful consideration. Such levels of variability are commonly observed in the rebound hammer test because the method evaluates only the near-surface layer of concrete and is influenced by factors such as surface finish, local aggregate distribution, and material heterogeneity. Consequently, rebound measurements may exhibit considerable scatter, particularly in young or non-uniform concrete. This variability highlights the need to interpret rebound results as approximate indicators of concrete quality rather than precise measures of strength, a matter that is discussed further in Section 4.4.

4.2 Surface Resistivity and Chloride Penetrability

Surface resistivity also increased steadily with age (Table 4, Fig. 2). M10 climbed from 5.36 kΩ·cm at 7 days to 8.57 kΩ·cm at 14 days and 13.08 kΩ·cm at 28 days, while M15 rose from 7.41 to 11.30 and then 18.52 kΩ·cm, with increases of about 144% and 150%, respectively, over the curing period. Interpreted against AASHTO T358, both mixes began in the "high" penetrability class at 7 and 14 days and improved to "moderate" by 28 days; neither reached the "low" class within the test window, which is expected for lean mixes containing no supplementary cementitious materials. The richer M15 was consistently the more resistive, by about 42% at 28 days, reflecting its lower water demand per unit binder and correspondingly finer, less connected pore structure (Layssi et al., 2015).

Table 4: Surface resistivity, scatter and AASHTO T358 penetrability class

Mix	Age (days)	Mean resistivity (kΩ·cm)	CoV (%)	Penetrability class
M10	7	5.36	18.6	High
M10	14	8.57	5.8	High
M10	28	13.08	5.0	Moderate
M15	7	7.41	8.9	High
M15	14	11.30	8.9	High
M15	28	18.52	5.4	Moderate

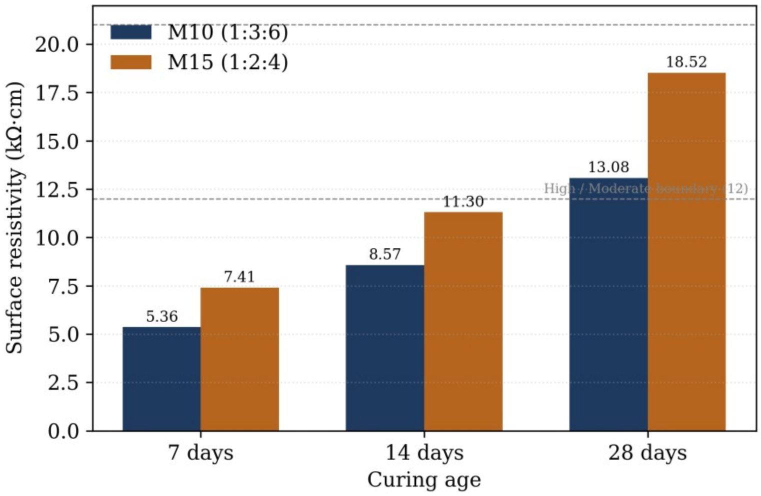

Fig. 2: Surface resistivity across curing ages for M10 and M15

Two features stand out. First, resistivity rose more steeply than strength in relative terms, indicating that pore-structure refinement outpaces surface-hardness gain over this period. Hydration closes capillary pathways faster than it raises the readily measured surface hardness. Second, and importantly for practice, the resistivity readings were far more repeatable than the rebound readings: coefficients of variation fell mostly between 5% and 9%, against 18-28% for the hammer. The four-point measurement samples a larger, deeper volume of material and is correspondingly less swayed by local surface effects.

To confirm that the observed gains were not artefacts of measurement scatter, one-way analysis of variance (ANOVA) was applied to the raw readings, testing whether curing age had a significant effect within each mix (Table 5). For rebound number, age was significant for both mixes (M10: $F = 3.70$, $p = 0.029$; M15: $F = 6.29$, $p = 0.003$). For surface resistivity, the effect was far stronger and highly significant (M10: $F = 244.1$; M15: $F = 348.8$; $p < 0.001$ in both cases). The much larger F-statistics for resistivity mirror its lower measurement scatter and confirm that it discriminates between curing ages more sharply than the rebound hammer does.

Table 5: One-way ANOVA for the effect of curing age within each mix

Mix	Property	F-statistic	p-value	Significant?
M10	Rebound number	3.70	0.029	Yes
M10	Surface resistivity	244.08	< 0.001	Yes
M15	Rebound number	6.29	0.003	Yes
M15	Surface resistivity	348.84	< 0.001	Yes

Pooling the six mixed-age groups, compressive strength and surface resistivity were strongly and positively related. Least-squares regression gave

$$f = 0.611\,\rho + 3.456 \quad (r = 0.933,\ R^2 = 0.870,\ p < 0.01)$$

so that resistivity accounts for about 87% of the variation in estimated strength, and each 1 kΩ·cm rise in resistivity corresponds to roughly a 0.61 N/mm² increase in strength. The slope is well determined, with a 95% confidence interval of 0.283 to 0.939 N/mm² per kΩ·cm and a standard error of estimate of only 1.25 N/mm². The scatter plot and fitted line are shown in Fig. 3. Fitting the grades separately further tightened the relationship. M10 followed $f_c = 0.479\rho + 3.743$ ($R^2 = 0.994$), and M15 followed $f_c = 0.529\rho + 5.385$ ($R^2 = 0.983$), indicating that a grade-aware calibration predicts strength from resistivity more reliably than a single pooled line, with the pooled relationship absorbing the offset between the two mixes.

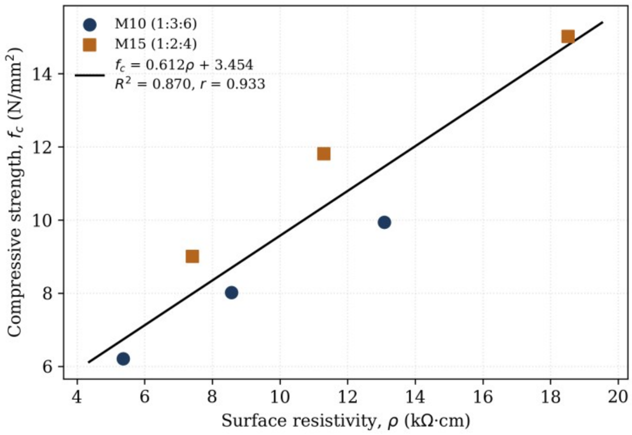

Fig. 3: Compressive strength against surface resistivity with fitted regression

The adequacy of the pooled model is shown in Fig. 4, where strengths predicted from resistivity are plotted against the observed values. All six points fall on or near the line of equality and within the ±1 SEE band, and the mean absolute percentage error is 9.5%, with the largest single deviation 1.5 N/mm². For practical use, the model is applied directly: a measured resistivity of, say, 10 kΩ·cm returns an estimated strength of $0.611 \times 10 + 3.456 \approx 9.6$ N/mm² while simultaneously placing the concrete in the "high" penetrability class, so a single resistivity reading yields both a strength estimate and a durability classification. When the mix grade is known, the grade-specific equation should be preferred for its narrower error.

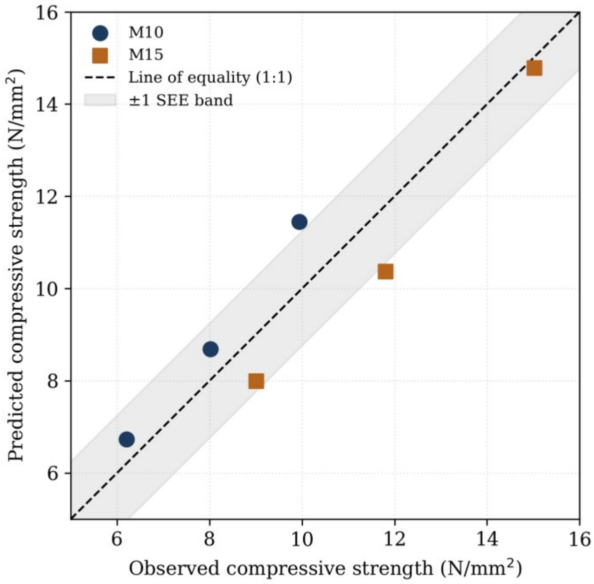

Fig. 4: Predicted versus observed compressive strength for the pooled model

It should be acknowledged that part of this correlation arises because both quantities are driven by the same underlying variable, curing age: strength correlated with age at $r \geq 0.98$ and resistivity at $r \geq 0.99$ for both mixes. The strength-resistivity association is therefore best read as evidence that the two indicators co-evolve through hydration, rather than as proof of a direct mechanical link between hardness and ionic resistance. That distinction does not diminish the practical value of the regression, but it does set the correct interpretation.

Taken together, the results show strength and resistivity improving in concert as curing proceeds, the joint signature of a maturing, densifying microstructure. At 7 days, both mixes were comparatively weak and freely penetrable, consistent with incomplete hydration and an open, connected pore system; by 28 days, pore refinement had appreciably increased both strength and resistivity (Gowers & Millard, 1999; Layssi et al., 2015). The agreement with the trends reported by Kim et al. (2025) and Castillo and Hedjazi (2024) supports the use of resistivity as a complementary, more repeatable screening measure alongside the rebound hammer.

Placing the present relationship against published work (Table 6) shows that its direction and durability implications are consistent with the recent literature. Studies on low-carbon, fibre-reinforced, and recycled-aggregate concretes have all reported that strength and resistivity rise together or that resistivity tracks chloride transport, while the documented unreliability of the rebound index for non-standard concrete reinforces the caution attached here to the absolute strength values.

Table 6: Comparison of the present correlation with published studies

Study	Material	Indicators/finding	Agreement
Present study	PLC concrete (M10, M15)	fc–resistivity, fc = 0.611ρ + 3.456, R^2 = 0.87	-
Kim et al. (2025).	Low-carbon concrete	Strength and resistivity increase together with age	Consistent
Castillo &Hedjazi (2024)	Fibre-reinforced concrete	Resistivity gives an empirical estimate of early-age strength	Consistent
Aragoncillo &Lomboy (2022)	Recycled-aggregate concrete	Resistivity correlates with chloride diffusivity and permeability	Consistent (durability link)
Revilla-Cuesta et al. (2022).	Recycled-aggregate SCC	Rebound index often inconsistent with true strength	Supports rebound caution

Equally, the findings carry two cautions that bear on acceptability for field use. The first concerns the rebound hammer itself: the estimated strengths here are low (6–15 N/mm²), a range in which the instrument is least reliable and in which the manufacturer's calibration is most strained, and the 18–28% reading scatter reinforces that these values are indicative. No destructive crushing was performed to anchor the rebound estimates, so the absolute strengths should be read with that limitation in mind, even though the relative trends are robust. The second is that resistivity, not strength, remains the more direct indicator of chloride resistance; the correlation lets one inform the other but does not make strength a guarantee of durability, echoing the long-standing caution of Andrade (1993) and Lian et al. (2011) that mechanical adequacy and durability, while correlated, are not interchangeable.

4.6 Limitations of the Study

Several boundaries should temper the interpretation of these results. Compressive strength was inferred solely from the rebound hammer and was not anchored by destructive cube crushing, so the absolute values, which fall in the low 6-15 N/mm² range where the instrument is least dependable, are best regarded as indicative; the relative trends and the resistivity data are considerably more secure. The study covered only two mixes at a single water-to-cement ratio and a single curing regime, and the correlation rests on six group means, so the regression should be treated as a calibrated trend rather than a universal formula. Finally, both indicators share curing age as a common driver, which inflates their apparent association; the relationship therefore documents co-development under hydration rather than a direct causal link between surface hardness and ionic resistance. These limitations frame the recommendations that follow and define the priorities for future work.

V. CONCLUSIONS

This study tracked the rebound-hammer compressive strength and four-point surface resistivity of M10 and M15 concrete at 7, 14, and 28 days of curing and examined their correlation. The main conclusions are as follows:

(i) Estimated compressive strength increased monotonically with curing age by about 60% for M10 (6.21 to 9.94 N/mm²) and 67% for M15 (9.01 to 15.02 N/mm²) between 7 and 28 days, with the richer M15 stronger at every age.

(ii) Surface resistivity rose by roughly 144-150% over the same period, carrying both mixes from the "high" into the "moderate" AASHTO T358 chloride-penetrability class; neither reached the "low" class within 28 days.

(iii) Strength and resistivity were strongly and significantly correlated ($fc = 0.611\rho + 3.456$; $r = 0.933$, $R^2 = 0.870$, $p < 0.01$), with grade-specific models fitting more tightly still ($R^2 \geq 0.98$).

(iv) Surface resistivity was substantially more repeatable than rebound readings (CoV ≈ 5-9% versus 18-28%), strengthening the case for resistivity as a complementary durability screen.

(v) The two non-destructive techniques can be used together for rapid, simultaneous screening of strength and chloride-penetrability during quality control, provided rebound estimates at low strengths are interpreted cautiously and, where possible, anchored by destructive checks.

Future work should extend testing to 56 and 90 days, anchor the rebound estimates against destructive cube crushing, broaden the range of mixes and water-to-cement ratios, incorporate supplementary cementitious materials, and validate the laboratory correlations under field exposure.

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