

## The effect of compaction method on the compressive strength and porosity of normal concrete

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*Received:* 21 November 2025; *Revised:* 19 January 2026; *Accepted:* 26 January 2026

 **Cite this** <https://doi.org/10.24036/jptk.v9i1.48723>

**Abstract:** This study investigates how community-like compaction practices affect density, porosity, and compressive strength of normal concrete across different workability levels. A factorial laboratory experiment (4 compaction methods × 3 slump targets) was conducted using 150×300 mm cylinders (n=72; six replicates per group). Concrete was proportioned to SNI 03-2834-2000; control compaction followed SNI 2493:2011; 28-day strength was tested per SNI 1974:2011; porosity was measured using an ASTM C642-based procedure. Slump was set at 5, 7, and 11 cm by varying water content. Fresh mass decreased as compaction became less effective, indicating lower achieved density and greater entrapped air: compared with SK, hammer vibration (SH) and no compaction (SP) were ~7–9% lighter. Porosity increased markedly under inadequate compaction, with SP reaching 22.36–26.81% versus 10.16–14.22% for SK. Compressive strength followed the same ordering: SK achieved 18.99–22.94 MPa, while SH and SP dropped to 9.90–13.93 MPa and 8.49–13.35 MPa, respectively, with losses up to ~58% relative to SK depending on slump. Overall, slump alone did not guarantee performance when compaction was poor. Rodding (SR) provided intermediate results, maintaining mass close to SK and limiting strength loss compared with SH/SP. An inverse porosity–strength relationship was observed across slumps.

**Keywords:** compaction method; normal concrete; compressive strength; porosity; slump; non-engineered construction

### 1. Introduction

Normal concrete in the range of 10–30 MPa is the most commonly used material for low-rise buildings and community housing, where construction quality is strongly influenced by field workmanship and practical constraints (Correal et al., 2018; Fantilli et al., 2019; Rahardjo et al., 2024). In community/non-engineered construction, concrete placement is typically executed by non-certified workers, with limited quality control, and often without access to internal vibrators, leading to compaction practices that deviate from standard procedures (Maryoto, 2018). As a result, concrete frequently exhibits high void content, brittle behavior, and compressive strength below the intended design performance. While material quality contributes to this problem, field implementation, particularly compaction practice, remains a critical and often underestimated determinant of concrete quality in these settings (Xu et al., 2022; Zhang et al., 2022).

Compaction directly governs the amount of entrapped air remaining in fresh concrete and therefore affects both mechanical capacity and durability. Proper compaction increases density by removing air voids, which improves compressive strength (Anburuvel & Subramaniam, 2022; Han et al., 2023; Zeng et al., 2021). It also improves durability by reducing pore volume and permeability, thereby enhancing resistance to fluid ingress and environmental deterioration (Ortiz-Marqués et

[al., 2025](#); [H. Zhao et al., 2025](#)). Conversely, poor compaction commonly results in concrete that fails to reach planned compressive strength, a condition frequently observed in low-rise and community housing projects ([Tutu et al., 2022](#)). This practical risk is reinforced by evidence that workmanship quality, including worker skill, significantly influences construction outcomes ([Alomari et al., 2020](#); [Boadu et al., 2020](#)). For reinforced concrete structures, reduced compressive strength can weaken structural performance; therefore, the earthquake/collapse context is relevant as motivation, but it is important to note that structural collapse probability is not measured in this experiment and is only used to frame the practical importance of achieving adequate concrete strength.

In practice, compaction may be performed through standard compaction (as regulated in SNI procedures), manual rodding, external vibration by hammering the formwork, or in some cases no compaction at all. These methods share the same objective, increasing density by minimizing internal voids, but differ substantially in effectiveness depending on workability and execution ([Daniel et al., 2024](#); [Juliafad et al., 2017](#)). Prior studies have investigated compaction effects mainly by varying vibration duration or examining rodding intensity, showing that insufficient compaction reduces compressive strength, while excessive vibration may not produce additional strength gains ([Cahyo et al., 2020](#); [Howes et al., 2019](#)). Further, ([Juliafad et al., 2019](#)) compared rodding and hammer vibration against standard compaction and confirmed that method choice influences compressive strength, although that study used limited sample numbers, a fixed mix proportion, and focused only on compressive strength of cubes.

Despite this progress, the evidence base still shows a clear limitation: prior work is disproportionately strength-focused, while simultaneous evaluation of compressive strength and porosity under community-like compaction practices (standard compaction vs rodding vs hammer vibration vs no compaction), particularly across different workability levels, remains insufficiently addressed. This matters because slump/workability interacts with compaction effectiveness: even when the target slump is achieved, inadequate compaction may still produce high void content, meaning slump alone does not guarantee quality. Therefore, examining both compressive strength and porosity together provides a more complete explanation of how field compaction practices shape concrete performance.

Accordingly, this study evaluates the effect of four compaction conditions commonly encountered in community construction, namely standard compaction (control), rodding, hammer vibration, and no compaction, on the compressive strength and porosity of normal concrete (10–30 MPa) at multiple slump targets. The study further examines the relationship between porosity and compressive strength to clarify how void formation under different compaction practices controls mechanical performance, and to provide evidence-based implications for improving concrete quality in non-engineered construction contexts.

## 2. Methods

### 2.1 Research design and standards

This study employed a quantitative experimental design to evaluate the effects of compaction method on the compressive strength and porosity of normal concrete. Mix proportioning and concrete production were conducted in accordance with SNI 03-2834-2000, while compressive strength testing followed SNI 1974:2011 ([Juliafad et al., 2019](#)). Specimen preparation and the standard compaction procedure for control samples were performed based on SNI 2493:2011 ([Maryoto, 2018](#)). Porosity measurements were standardized using an ASTM C642-based procedure. The overall experimental workflow is presented in Figure 1.

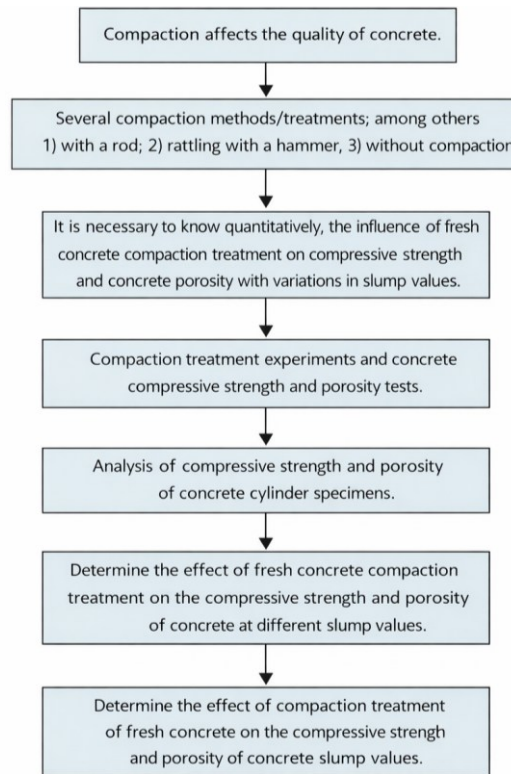


Figure 1. Research workflow

## 2.2 Materials

Fine aggregate (sand) was sourced from Lubuk Alung, Padang Pariaman Regency, West Sumatra, with moisture content of 1.58% and mud content of 3.59%. The fine aggregate met ASTM C33 requirements. The sand specific gravity (SNI 1970:2008) was 2.38, and sieve analysis confirmed compliance with gradation limits (Figure 2). The cement used was Type I Ordinary Portland Cement (50 kg commercial bags produced in Padang). Coarse aggregate was locally available crushed stone (properties reported in the laboratory log and used consistently across all mixes). Mixing water was clean potable water.

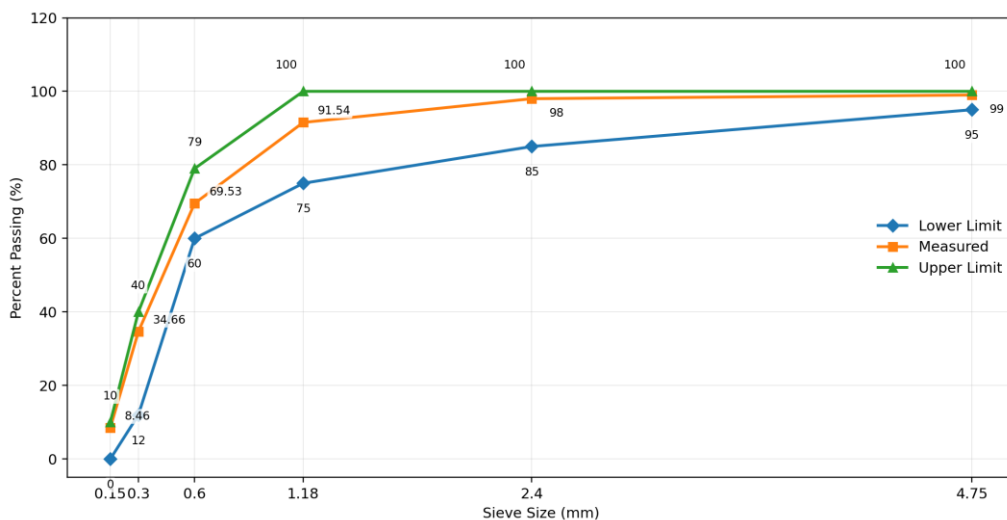


Figure 2. Sand gradation curve (sieve analysis)

### 2.3 Specimens, factors, and sample size

Concrete cylinders with diameter 150 mm and height 300 mm were cast. The experimental factors were:

1. Compaction method (4 levels): Standard compaction/control (SK), Rodding (SR), Hammer vibration (SH), No compaction (SP)
2. Slump target (3 levels): 5 cm, 7 cm, and 11 cm

For each combination,  $n = 6$  cylinders were produced, resulting in 72 specimens (4 methods  $\times$  3 slump levels  $\times$  6 replicates). All cylinders were tested at 28 days for compressive strength and porosity. Sample distribution is shown in Table 1.

**Table 1.** Specimen matrix/sample size (n) per group

Type of samples	Test type	Number of samples		
		Slump		
		5	7	11
Control Sample	Compressive strength and porosity	6	6	6
Rodding		6	6	6
Hammer		6	6	6
No Compaction		6	6	6
Number of Samples		72		

### 2.4 Mix design and slump control (complete and consistent reporting)

A single base mix (cement, fine aggregate, and coarse aggregate quantities) was kept constant, and workability (slump) was adjusted by varying the water content, producing different w/c ratios (FAS) per slump target. No chemical admixtures were used (unless otherwise stated; if admixtures are used, report type/dosage and revise this sentence). Per cylinder (15 $\times$ 30 cm), material quantities were:

- Cement: 1.782 kg
- Fine aggregate: 3.142 kg
- Coarse aggregate: 5.835 kg
- Water: adjusted to achieve slump target

Water quantities were corrected to remove inconsistencies and to match the target slumps as follows:

- Slump 5 cm (Low workability): 835 mL water per cylinder
- Slump 7 cm (Medium workability): 1041.7 mL water per cylinder
- Slump 11 cm (High workability): 1166.67 mL water per cylinder

### 2.5 Casting and compaction procedures (standardized)

Concrete was placed into molds and treated using one of the following:

1. SK (standard control): 3 layers; each layer rodded 25 times using a 16 mm steel rod per SNI 2493:2011 ([Maryoto, 2018](#)).
2. SR (rodding): 3 layers; each layer rodded 25 times with uniform distribution and penetration into the underlying layer.
3. SH (hammer vibration): external vibration by striking the mold at 3 vertical levels ( $\approx 10, 20, 30$  cm) and 4 directions per level ([Juliafad et al., 2019](#)). Report fixed hammer type/mass and total blows per point (N) to ensure reproducibility.
4. SP (no compaction): poured into the mold with no rodding/vibration.

## 2.6 Curing and conditioning

Specimens were demolded after initial setting (state the exact time used) and cured by water immersion until 28 days. Report curing water temperature (or range) and handling procedure. Prior to testing, specimens were surface-dried and conditioned for strength/porosity tests.

## 2.7 Compressive strength test

At 28 days, compressive strength was tested using an ELE Compression Testing Machine following SNI 1974:2011 ([Maryoto, 2018](#)).

## 2.8 Porosity test

Porosity was measured using an ASTM C642-style procedure with three masses:

- C: oven-dry mass ( $105 \pm 5^\circ\text{C}$  to constant mass)
- B: saturated surface dry (SSD) mass after soaking for a fixed duration (report duration)
- A: submerged mass in water

Porosity (%) was computed as shown in Equation (1).

$$\text{Porosity (\%)} = (B - C)/(B - A) \quad (1)$$

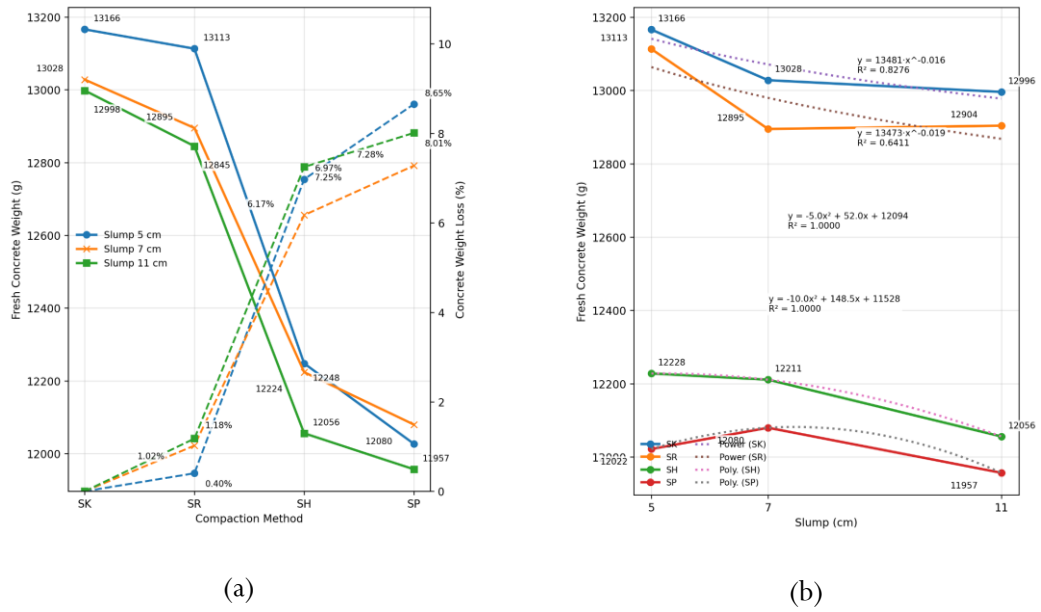
This is consistent with standard pore-volume interpretation ([Maryoto, 2018](#)).

## 3. Results

### 3.1 Fresh concrete mass as an indicator of entrapped air and compaction effectiveness

Fresh concrete mass (measured prior to curing) varied systematically across compaction treatments and slump levels, reflecting differences in achieved density and the likely amount of entrapped air. For the control treatment compacted according to SNI (SK), the fresh mass at slump 5 cm was 13,166 g and decreased slightly as slump increased to 13,028 g at slump 7 cm ( $-1.05\%$ ) and 12,996 g at slump 11 cm ( $-1.29\%$ ) (Figures 3a and 3b). Rodded specimens (SR) remained close to the control, with fresh masses of 13,113 g (slump 5), 12,895 g (slump 7), and 12,845 g (slump 11), indicating only small reductions relative to SK at comparable slump levels. In contrast, hammer vibration (SH) produced consistently lower fresh mass than SK, for example 12,228 g at slump 5 ( $\approx -7.1\%$  vs SK) and 12,056 g at slump 11 ( $\approx -7.2\%$  vs SK), suggesting less effective air removal. The lowest masses were observed for specimens without compaction (SP), including 12,022 g at slump 5 ( $\approx -8.7\%$  vs SK) and 11,957 g at slump 11 ( $\approx -8.0\%$  vs SK). Overall, the pattern across Figures 3a supports the interpretation that reduced compaction effectiveness is associated with

lower fresh density, consistent with greater entrapped air and internal void formation.

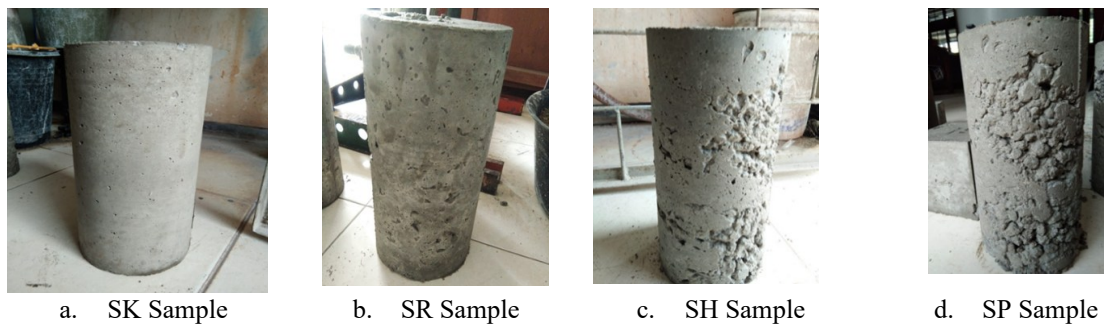


**Figure 3.** (a) Fresh concrete weight and relative weight loss (%) across compaction methods at different slump values and (b) Fresh concrete weight as a function of slump for each compaction method (with fitted trendlines)

Figure 3b complements these findings by showing that fresh mass generally decreases as slump increases for each compaction treatment, although the strength of the trend varies by method. Importantly, differences between SK/SR versus SH/SP indicate that workability alone does not determine fresh density; compaction effectiveness remains a dominant contributor to entrapped-air conditions, particularly under community-like practices.

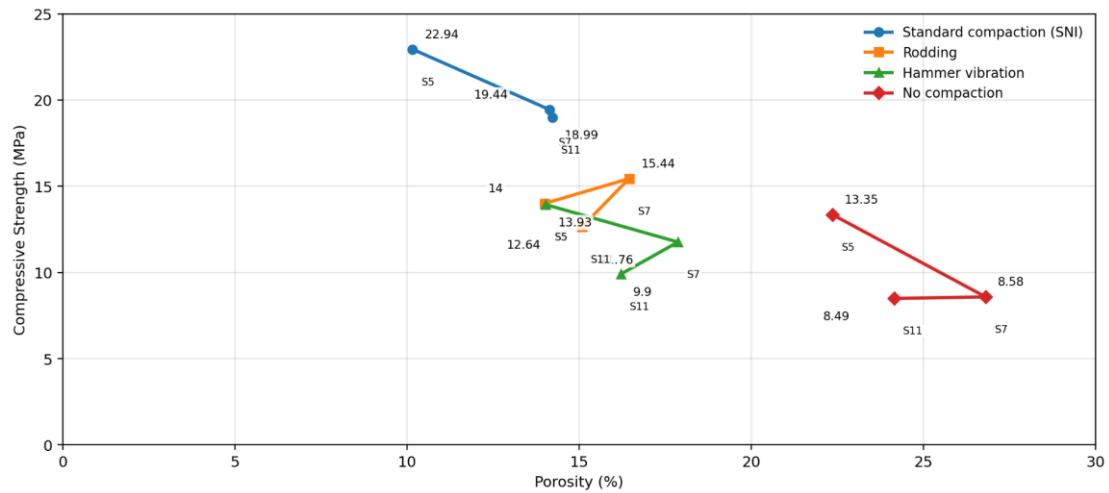
### 3.2 Effect of compaction method on concrete porosity

Figure 4 provides qualitative support for the quantitative porosity findings. SK specimens show smoother, denser surface finishes, whereas SR specimens display slightly more surface voids. SH specimens present more exposed aggregate texture, and SP specimens exhibit deeper cavities and clearer signs of void concentration. Taken together, Figures 5–6 reinforce the interpretation that reduced compaction effectiveness increases entrapped air and void development, which is reflected both in measured porosity and observable surface integrity.



**Figure 4.** Visualization of the concrete cylinder surface on the specimen with various compaction methods

Porosity results, determined using ASTM C642 mass states (oven-dry C, SSD B, and submerged A), show a consistent effect of compaction treatment on the internal void content of hardened concrete. At slump 5 cm, porosity was lowest for standard compaction (SK = 10.16%), increased for rodding (SR = 14.00%) and hammer vibration (SH = 14.03%), and was substantially higher without compaction (SP = 22.36%). The same pattern persisted at slump 7 cm (SK = 14.14%, SR = 16.45%, SH = 17.87%, SP = 26.81%) and slump 11 cm (SK = 14.22%, SR = 15.08%, SH = 16.21%, SP = 24.15%). Overall, these results indicate that no compaction (SP) consistently produces the highest porosity across all slump levels, while standard compaction (SK) yields the lowest porosity, confirming that compaction effectiveness is a dominant factor governing internal void formation in Figure 5.

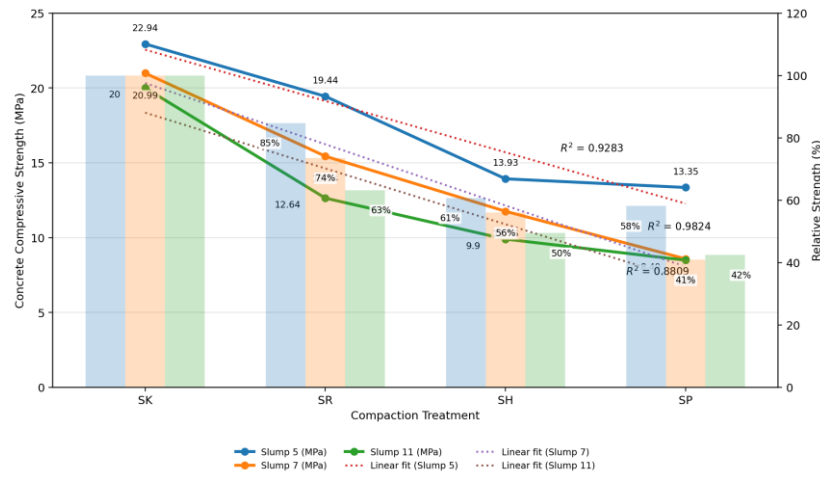


**Figure 5.** Correlation between concrete porosity (%) and compressive strength (MPa) for different compaction treatments

### 3.3 Effect of compaction method on compressive strength across slump levels

At 28 days, compressive strength decreased systematically as compaction became less effective in Figure 6. At slump 5 cm, the control specimen compacted according to SNI (SK) achieved 22.94 MPa, whereas SR, SH, and SP decreased to 14.00 MPa, 13.93 MPa, and 13.35 MPa, representing reductions of 38.97%, 39.27%, and 41.80% relative to SK. At slump 7 cm, SK reached 18.99 MPa; SR remained comparatively closer at 15.44 MPa (-18.69%), while SH and SP dropped to 11.76 MPa (-38.07%) and 8.58 MPa (-54.81%). At slump 11 cm, SK was 20.00 MPa, but strength declined to 12.64 MPa for SR (-36.80%), 9.90 MPa for SH (-50.50%), and 8.49 MPa for SP (-57.55%). Overall, rodding (SR) partially preserved strength relative to standard compaction, whereas hammer vibration (SH) and especially no compaction (SP) produced pronounced strength loss, consistent with greater entrapped air and internal void formation indicated by the porosity results.

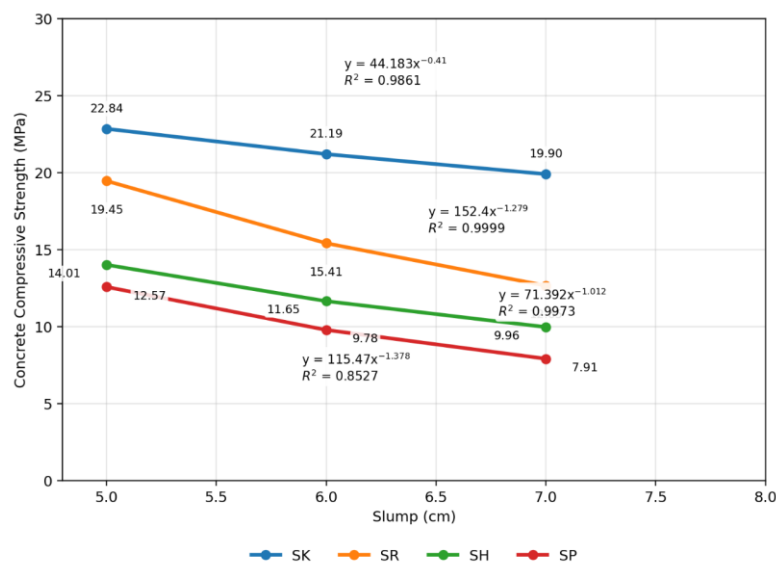
These results highlight that workability (slump) alone does not guarantee compressive performance when compaction is inadequate; compaction effectiveness remains the dominant determinant of hardened concrete strength under non-standard field practices.



**Figure 6.** Effect of compaction treatment on concrete compressive strength (MPa) across slump levels, with relative strength (%) referenced to SK

### 3.4 Linking porosity to strength: a consistent inverse relationship

Across all slump levels, higher porosity was consistently associated with lower compressive strength, indicating an inverse relationship between void content and load-bearing capacity in Figure 4. Mechanistically, increased porosity reduces the effective resisting area and introduces stress concentration zones, while weakening the interfacial transition zone between aggregate and cement paste. The ordering of compaction treatments was also consistent with this pattern: standard compaction (SK) produced the lowest porosity and the highest compressive strength, rodding (SR) showed intermediate performance, and both hammer vibration (SH) and no compaction (SP) tended to yield higher porosity with lower strength. These findings support prior evidence that inadequate compaction increases entrapped air and void formation, leading to substantial strength loss (Ma et al., 2026; Utkarsh & Jain, 2024), and align with experimental reports showing that non-standard compaction practices can markedly reduce compressive strength compared with standard compaction (Juliafad et al., 2017).

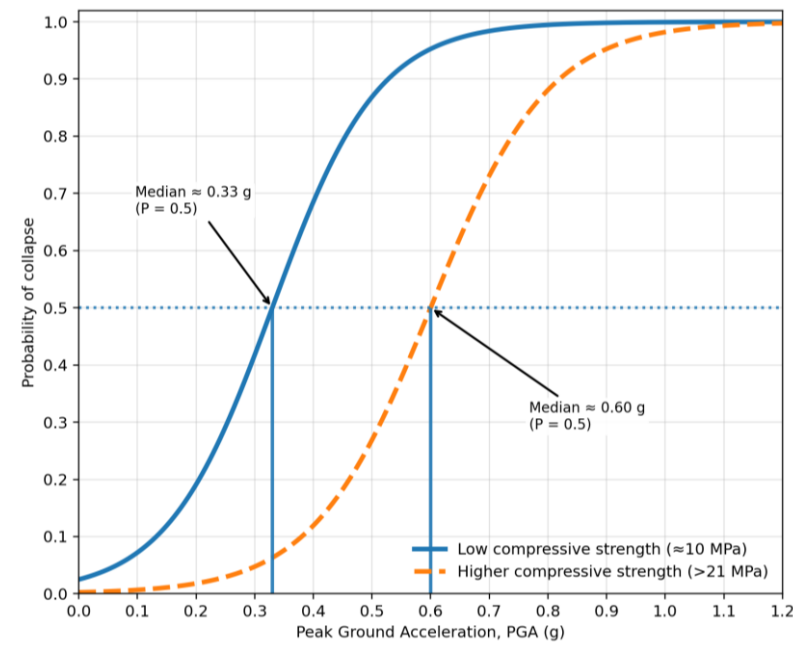


**Figure 7.** Relationship between slump (cm) and concrete compressive strength (MPa) for different compaction treatments

Figure 7 complements this interpretation by showing that compressive strength generally decreases as slump increases within each treatment, but the separation between SK/SR and SH/SP indicates that workability alone does not determine strength. In other words, even at comparable slump levels, less effective compaction is associated with lower strength, consistent with greater void content as reflected in the porosity results.

### 3.5 Practical implications and structural risk context

From a practical standpoint, the strength reductions observed under less effective compaction have direct implications for reinforced-concrete performance in low-rise and community construction, where quality control is often constrained by workmanship and limited equipment. Lower compressive strength reduces axial capacity and stiffness, and increases vulnerability to cracking and excessive deformation, which can compromise structural performance under service loads and seismic demand. Figure 8 is included to contextualize this risk: the fragility curves indicate that buildings with low concrete strength ( $\approx 10$  MPa) reach a median collapse probability ( $P = 0.5$ ) at approximately 0.33 g, whereas those with higher concrete strength ( $>21$  MPa) reach the same probability at approximately 0.60 g. Although these curves are not measured in the present experiment, they illustrate why achieving adequate compressive strength in practice matters for seismic resilience. Taken together with the experimental findings, the results reinforce that non-standard compaction practices can substantially reduce compressive strength while increasing porosity, underscoring compaction quality as a controllable field variable. Therefore, improving outcomes in non-engineered construction requires feasible compaction procedures, basic supervision/checklists, and practical guidance that can be implemented consistently on site.



**Figure 8.** Fragility curves showing the probability of collapse versus peak ground acceleration (PGA) for reinforced concrete buildings

## 4. Discussion

This study provides integrated evidence that compaction practice, rather than workability alone, is a primary determinant of normal concrete performance in community/non-engineered construction contexts. Across slump targets (5, 7, and 11 cm), less effective compaction

consistently reduced fresh concrete mass (indicating lower achieved density), increased hardened porosity, and lowered 28-day compressive strength. The ordering of outcomes was stable across tests: SK produced the highest density/lowest porosity/highest strength, SR remained closer to SK, while SH and especially SP showed systematically poorer performance. These findings reinforce concerns that field workmanship and practical constraints can undermine concrete quality in low-rise/community housing where standard equipment and quality control are limited ([Maryoto, 2018](#); [Rahardjo et al., 2024](#); [Xu et al., 2022](#); [Zhang et al., 2022](#)).

Mechanistically, the combined density–porosity–strength pattern supports a coherent explanation: inadequate compaction leaves more entrapped air and internal voids, reducing the effective load-bearing area and creating stress concentration zones, while also weakening the interfacial transition zone between aggregate and cement paste. This aligns with prior evidence that proper compaction improves compressive strength by increasing density ([Anburuvel & Subramaniam, 2022](#); [Han et al., 2023](#); [Zeng et al., 2021](#)) and improves durability by reducing pore volume and permeability ([Ortiz-Marqués et al., 2025](#); [H. Zhao et al., 2025](#)). Conversely, poor compaction is widely recognized as a major source of under-strength concrete in practice ([Tutu et al., 2022](#)), and the present results show this risk clearly under compaction treatments that mirror community practices.

Compared with previous work, this study extends the evidence base in two important ways. First, earlier studies often emphasized strength outcomes under variations of vibration duration or rodding intensity, generally concluding that insufficient compaction reduces strength while excessive vibration may yield diminishing returns ([Cahyo et al., 2020](#); [Howes et al., 2019](#)). Here, the method contrast is broader and closer to field reality (standard compaction vs rodding vs external hammer vibration vs no compaction), and the patterns demonstrate that hammer vibration and no compaction produce pronounced strength penalties across slump levels, while rodding partially preserves performance. Second, prior comparisons of rodding and hammer vibration against standard compaction have documented method sensitivity but were commonly limited by narrow sample sizes, fixed mix designs, and strength-only outcomes ([Juliafad et al., 2019](#)). By evaluating compressive strength together with porosity across multiple slump targets, the present study provides a more complete account of how compaction controls void development and thereby governs mechanical capacity, consistent with the broader understanding of porosity-strength coupling in concrete ([Nguyen, 2024](#); [J. Zhao et al., 2025](#)).

A key practical implication is that slump/workability should not be treated as a proxy for concrete quality when compaction is inadequate. Although higher slump tends to reduce strength within each method, the separation between SK/SR and SH/SP indicates that compaction effectiveness remains dominant: concrete can be workable yet still highly porous and under-strength if air is not removed. This directly matters in community housing where workmanship, supervision, and equipment availability constrain construction quality ([Alomari et al., 2020](#); [Boadu et al., 2020](#)). The seismic-risk framing (fragility curves) is therefore relevant as motivation: while structural collapse probability was not measured here, the literature suggests that low compressive strength is associated with substantially earlier collapse under seismic demand, highlighting why compaction practice is a controllable and high-impact field variable ([Correal et al., 2018](#); [Fantilli et al., 2019](#); [Rahardjo et al., 2024](#)).

Finally, the results point to actionable directions for both practice and research. For practice in non-engineered contexts, the findings support prioritizing feasible compaction procedures (standardized rodding where vibrators are unavailable), simple supervision/checklists, and training to reduce variability in execution ([Daniel et al., 2024](#); [Maryoto, 2018](#)). For research, reproducibility would be strengthened by reporting hammer type/mass and the number of blows per point in SH, and by

extending evaluation to durability-relevant indicators such as permeability and fluid ingress, given the porosity differences observed ([Ortiz-Marqués et al., 2025](#); [H. Zhao et al., 2025](#); [J. Zhao et al., 2025](#)). Overall, by jointly analyzing density signals, porosity, and compressive strength under community-like compaction practices, this study helps move the discussion from “strength differences” toward a clearer causal pathway: compaction to void content to mechanical performance, which is the central mechanism that must be managed in the field.

## 5. Limitations

This study was conducted under controlled laboratory conditions using a single base mix design, one cement type, and locally sourced aggregates, which limits generalizability to other material sources, mix proportions, and site conditions commonly encountered in community construction. Although three slump targets were examined, slump was adjusted only by varying water content (w/c ratio), without considering admixtures or alternative workability control strategies that are increasingly used in practice. In addition, the external hammer vibration treatment (SH) represents a community-like method, but reproducibility may be affected if key operational parameters (e.g., hammer type/mass, number of blows per point, and striking consistency) are not tightly standardized and fully reported. The porosity measurement followed an ASTM C642-style approach, which captures accessible pore volume by mass states but does not distinguish pore-size distribution or connectivity; therefore, microstructural characterization (e.g., image-based void analysis) and transport metrics (e.g., permeability) remain outside the scope of this study. Finally, the structural risk framing using fragility curves is included only for contextual motivation and is not derived from the present experimental dataset; collapse probability or structural response under seismic loading was not tested.

## 6. Conclusion and future insights

This study demonstrates that compaction practice is a dominant determinant of normal concrete performance in community-like construction conditions, and that workability (slump) alone does not guarantee quality when compaction is inadequate. Across slump targets of 5, 7, and 11 cm, reduced compaction effectiveness consistently lowered fresh concrete mass (indicating lower achieved density), increased hardened porosity, and reduced 28-day compressive strength. Standard compaction (SK) produced the lowest porosity and highest strength, rodding (SR) partially preserved performance, while hammer vibration (SH) and especially no compaction (SP) resulted in substantially higher void content and pronounced strength loss. The consistent inverse association between porosity and compressive strength supports a clear mechanism: inadequate compaction increases entrapped air and void development, which controls mechanical capacity and likely durability. Practically, these findings reinforce that improving concrete quality in non-engineered contexts requires feasible compaction procedures, basic supervision/checklists, and training to reduce execution variability, consistent with prior evidence linking workmanship to construction outcomes. Future work should strengthen reproducibility by fully standardizing and reporting SH execution parameters, extend testing to durability-related indicators (e.g., permeability, absorption, and fluid ingress), and examine a broader range of mixes and field-relevant conditions, including admixture-based workability control and multi-site validation under community construction constraints.

## Author's declaration

### Author contribution

**Yose Fajar Pratama:** Conceptualization; Methodology; Investigation (mix design, casting, compaction treatments, curing); Data curation; Laboratory testing (compressive strength and porosity); Formal analysis; Visualization; Writing original draft. **Eka Juliafad:** Conceptualization; Methodology; Supervision; Validation (experimental procedure and interpretation); Resources (laboratory facilities); Writing review & editing.

### Funding statement

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

### Data availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

### Acknowledgements

The authors gratefully acknowledge the Department of Civil Engineering, Faculty of Engineering, Universitas Negeri Padang, for providing laboratory facilities and testing equipment to support specimen preparation, curing, and 28-day compressive strength and porosity testing.

### Conflict of interest

The author declares no competing interests.

### Ethical clearance

Not applicable.

### AI statement

The authors used a grammar-checking tool like Quillbot to improve language clarity. The tool was not used to generate scientific content. All research content, experimental procedures, calculations, analysis, tables, and figures were produced and verified by the authors.

## Publisher's and Journal's note

Universitas Negeri Padang as the publisher, and the Editor of Jurnal Pendidikan Teknologi Kejuruan state that there is no conflict of interest towards this article publication.

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