

Experimental Investigation on Reactive Powder Concrete

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Abstract: This paper studies how floor height variation affects the seismic behavior of a G+10 RCC building using ETABS. In modern cities, reinforced concrete buildings are often built with different floor heights for parking, commercial space, or architectural needs. While this is useful in practice, it can change how the building behaves during an earthquake. This study examines the effect of floor height variation on the seismic performance of a G+10 RCC building using ETABS. Three cases are studied: a uniform-height building, a soft-storey building with a taller ground floor, and a building with alternate floor height variation. The results show that floor height variation increases the fundamental time period and lateral displacement, while reducing base shear. It also increases drift at the irregular storey, especially in the soft-storey model. These findings show that vertical irregularity should be carefully considered in seismic design, because even if strength demand seems lower, serviceability and safety may become critical.

Keywords: Reactive Powder Concrete (RPC), Rice Husk Ash (RHA), Quartz powder, Micro steel fibres, High-performance concrete, Compressive strength, Particle packing, Durability.

I. INTRODUCTION

The demand for durable and high-strength materials in modern infrastructure has pushed concrete technology beyond the limits of conventional mixes based on coarse aggregates and relatively high water-binder ratios. Ordinary concrete, though widely used, suffers from low tensile strength, a vulnerable interfacial transition zone (ITZ), high permeability, and susceptibility to environmental deterioration, which together reduce service life and increase maintenance costs. High-performance concrete (HPC) has improved these properties to some extent, but it still relies on a coarse aggregate skeleton and cannot fully eliminate the weak ITZ and interconnected pore network.

Reactive Powder Concrete (RPC) emerges as a next-generation ultra-dense cementitious material that removes coarse aggregates entirely and uses only fine sand, micro-fillers, and highly reactive pozzolanic materials to achieve exceptional particle-packing density. By restricting aggregate size to a narrow fine range and combining cement, silica-rich additives, and quartz powders, RPC significantly reduces internal voids and refines the pore structure, resulting in very low permeability and enhanced resistance against aggressive chemical agents. The inclusion of short, high-tensile steel fibres transforms the brittle cement matrix into a ductile composite, providing crack-bridging, strain-hardening, and improved energy absorption under loading.

Despite laboratory reports of compressive strengths exceeding 150 MPa, the field implementation of RPC faces challenges related to high material costs and the absence of standardized mix design guidelines. Proprietary ingredients such as high-purity silica fume, refined quartz flour, and commercial micro steel fibres increase cost, while the lack of codified procedures forces engineers to rely on trial-and-error mix design. There is a clear need to develop cost-effective RPC mixes using locally available materials and industrial by-products, while maintaining high strength and durability. In this context, the present work focuses on experimentally developing an RPC-type mix using OPC 53-grade cement, locally available Rice Husk Ash, quartz powder, fine sand, PCE-based superplasticizer, and micro steel fibres. The study evaluates compressive strength at 7, 14, and 28 days under standard curing, benchmarks performance against conventional concrete, and analyses the microstructural contributions of individual constituents, with an emphasis on practical limitations that prevent the mix from reaching the true ultra-high-performance range.

II. LITERATURE REVIEW

Richard and Cheyrezy first introduced Reactive Powder Concrete as an ultra-high-performance cementitious composite that eliminates coarse aggregates, optimizes fine particle packing, and achieves compressive strengths exceeding 200

MPa with very low permeability. Subsequent microstructural investigations showed that the combination of ultra-low water-binder ratio, highly reactive silica fume, and quartz powder produces a very dense matrix with minimal porosity and a significantly refined ITZ. These studies established the fundamental concept of RPC as a matrix-dominated composite where strength is governed by microstructure rather than by a coarse aggregate skeleton.

Several researchers have investigated fibre-reinforced RPC and ultra-high-performance concrete (UHPC) elements in structural applications such as beams, girders, and columns. Experimental work on fiber-reinforced RPC girders has demonstrated that randomly distributed steel fibres can replace or substantially reduce conventional shear reinforcement by bridging cracks, enhancing shear capacity, and controlling crack widths. Other studies on axially loaded RPC columns have reported improved load-carrying capacity and ductility due to the homogeneous matrix and the micro-confinement provided by the fibre network. Investigations on torsional behaviour and combined loading further highlight the superior crack-bridging and energy dissipation capabilities of fibre-reinforced ultra-high-performance concretes.

Recent research has also focused on sustainability and cost reduction in RPC/UHPC by partially replacing cement or silica fume with industrial by-products such as fly ash, Rice Husk Ash, and recycled glass powder. These materials, rich in amorphous silica, participate in pozzolanic reactions, producing additional Calcium Silicate Hydrate (C-S-H) gel and contributing to matrix densification and long-term strength development. Studies have shown that, with careful particle-packing optimization, locally sourced materials can produce high-performance mixes with mechanical and durability properties comparable to proprietary RPC formulations.

Comprehensive reviews of Ultra-High-Performance Ductile Concrete (UHPdC) and related systems emphasize the critical role of fibre type, volume fraction, aspect ratio, and distribution in governing post-cracking tensile behaviour, ductility, and energy absorption. At the same time, authors have highlighted gaps related to standardized mix design procedures, field curing regimes, and long-term durability data, indicating the need for further experimental work on sustainable, locally optimized RPC mixes. The present study contributes to this body of work by focusing on an RPC-type mix incorporating RHA and quartz powder under realistic laboratory curing conditions.

III. METHODOLOGY

The research adopts an experimental, quantitative approach to develop and evaluate a high-strength RPC-type mix using locally available raw materials and standard laboratory facilities. The methodology is structured to capture the influence of key input variables—such as water-binder ratio, RHA dosage, quartz powder content, and steel fibre volume—on the primary output variable of compressive strength. The overall framework covers material characterization, mix design, specimen preparation, curing, and mechanical testing.

OPC 53-grade cement is used as the primary binder to ensure high early strength and a dense hydration product. Rice Husk Ash, rich in amorphous silica, serves as a supplementary cementitious material that reacts with calcium hydroxide to form secondary C-S-H gel, thereby refining the microstructure and improving durability. Quartz powder, with a controlled fine particle size range, is employed as an inert micro-filler to further enhance particle packing and reduce micro-voids between cement and RHA grains. Fine river sand, strictly limited to the 150–600 μm range, replaces conventional coarse aggregates and forms the only granular skeleton, eliminating the weak ITZ associated with large aggregate particles.

A PCE-based high-range water-reducing admixture is introduced to achieve workable rheology at a very low water-binder ratio, promoting dispersion of fine particles and minimizing the need for excess water. Micro straight steel fibres of approximately 13 mm length and high tensile strength (around 2250 MPa) are added to enhance tensile strength, ductility, and post-cracking behaviour. Standard IS and relevant testing guidelines are followed to determine key physical properties such as specific gravity, fineness, and pozzolanic activity indices, ensuring compatibility and quality control of all constituents.

The experimental matrix uses nine 150 mm cube specimens to map compressive strength development at 7, 14, and 28 days, with three replicate specimens at each age to allow reliable averaging and assessment of variability. Data collection involves recording failure loads, computing compressive strengths, and analysing strength evolution and percentage gains between ages. The methodology is designed to reflect realistic laboratory conditions, with standard immersion curing and vibration-based compaction, rather than specialized high-temperature curing, to highlight practical performance limits.

IV. EXPERIMENTAL PROGRAM

The experimental program begins with detailed material characterization and proceeds through mix proportioning, batching, casting, curing, and compressive strength testing. OPC 53-grade cement is tested in accordance with IS 12269 to determine specific gravity, standard consistency, setting times, and fineness, confirming its suitability for high-strength applications. Rice Husk Ash is evaluated against pozzolanic performance parameters analogous to IS 1727, revealing a high silica content (around 89.4%) and a favourable pozzolanic activity index. Quartz powder, fine sand, superplasticizer, and steel fibres are similarly characterized for key physical parameters such as particle size, specific gravity, and tensile strength.

The optimized RPC mix is designed using particle-packing principles rather than conventional empirical charts, with the aim of eliminating coarse aggregates and maximizing matrix density. The selected mix uses a cement ratio of 1.00 combined with RHA, limestone/quartz fillers, fine sand, a low water-binder ratio of about 0.23, PCE superplasticizer, and approximately 0.19 parts steel fibres by mass ratio, yielding a total batch mass of around 82.49 kg for nine cubes including a 10% wastage factor. The mix design targets a highly cohesive yet workable paste capable of proper mould filling and fibre dispersion under vibration.

A controlled dry-to-wet mixing sequence is adopted: first, cement, RHA, quartz powder, and fine sand are dry-mixed for about 3 minutes to ensure uniform dispersion; then the water–superplasticizer solution is gradually added over several minutes to form a homogeneous paste; finally, steel fibres are introduced slowly to prevent balling and are mixed until evenly distributed. The fresh mix is placed into 150 mm cube moulds in layers and compacted using a laboratory vibration table to expel entrapped air and densify the matrix around the fibres. After initial setting in the moulds for 24 hours at room temperature, cubes are demoulded and submerged in clean water at controlled temperature until the testing ages of 7, 14, and 28 days.



Fig 4.1: Material used in Experiment

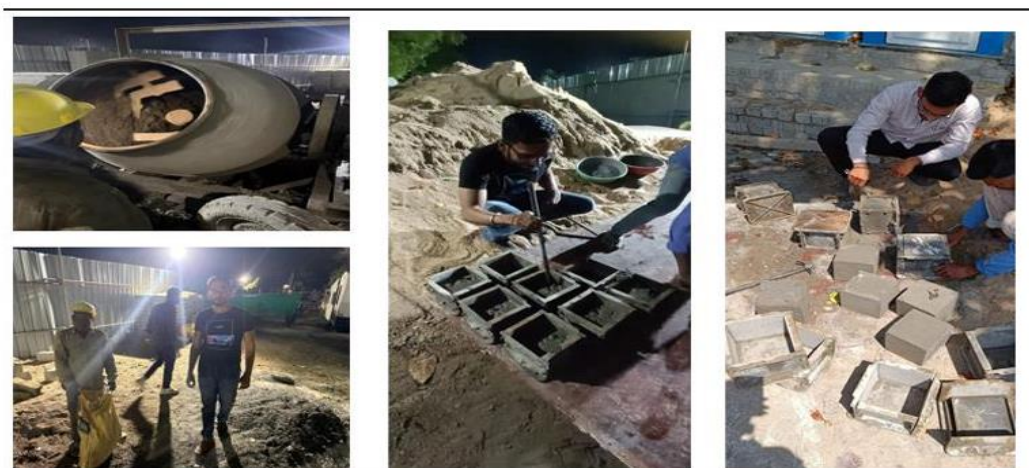


Fig 4.2: Moulds casting and demolding

Compressive strength tests are carried out using a calibrated Compression Testing Machine (CTM) following standard loading rates and alignment procedures. Each cube is loaded monotonically to failure, and the maximum load is recorded and converted to compressive strength based on the loaded area. The results for individual specimens are compiled into a test matrix, and age-wise average strengths and percentage gains relative to the 28-day strength are computed for analysis.

Table I. Optimized RPC mix design

Material component	Mix design ratio by mass
Cement	1.00
Rice Husk Ash (RHA)	0.29
Limestone / Quartz powder	0.25
Fine sand	1.38
Water	0.23
Superplasticizer (PCE)	0.03
Micro steel fibres	0.19

V. RESULTS AND DISCUSSION

The optimized RPC mix demonstrates a substantial improvement in compressive strength compared to conventional concrete grades, with the 28-day average compressive strength reaching about 69.40 MPa and individual values around 68.90–70.20 MPa. This strength level corresponds to roughly 2.3–3.4 times the capacity of typical M20–M30 structural concretes, confirming the mix as a high-performance concrete suitable for heavily loaded applications. However, the achieved strength remains below the 100–150 MPa range associated with standard RPC, highlighting the influence of curing and processing constraints.

The strength development curve shows an aggressive early-age hydration phase followed by a pronounced plateau. The average strength increases from about 47.77 MPa at 7 days to 67.80 MPa at 14 days, representing a gain of roughly 41.93% in a single week. This rapid development is attributed to the high reactivity of OPC 53-grade cement and the pozzolanic action of RHA, which together generate substantial amounts of C-S-H gel and densify the matrix in the early curing period. Between 14 and 28 days, however, the strength gain is limited to about 2.36%, indicating that hydration slows significantly under standard water immersion curing and that quartz powder largely remains as an inert filler rather than participating in further pozzolanic reactions at ambient temperature.

Table II. Compressive strength at different curing ages

Curing age (days)	Average compressive strength (MPa)	Percentage of 28-day strength (%)
7	47.77	68.8
14	67.80	97.7
28	69.40	100.0

The microstructural contribution of individual constituents can be interpreted from the observed performance. RHA, with its fine particle size and high silica content, reacts with calcium hydroxide to form additional C-S-H, thereby refining pore connectivity and improving durability potential. Quartz powder improves particle packing by filling micro-voids between cement and RHA particles, increasing matrix density, but its reactive potential is not fully exploited without elevated-temperature curing. Steel fibres bridge micro-cracks, delay crack propagation, and provide a more ductile post-peak response, which is essential in preventing brittle failure in high-strength cementitious matrices.

The study also identifies key factors that prevented the mix from reaching ultra-high-performance RPC strength levels. The absence of accelerated thermal curing, such as steam curing at around 90 °C or autoclaving, limits late-age pozzolanic reactions and keeps some quartz fractions inert. To maintain workable rheology with the available superplasticizer dosage, a slightly higher effective water-binder ratio was required, and the evaporation of this additional water left behind micro-capillary pores that reduce attainable strength. Standard laboratory vibration tables, while adequate for normal concretes, do not provide the extreme compaction energy required to fully expel entrapped air from a dense, fibre-rich RPC matrix, allowing residual voids to persist.

Table III. Comparison with conventional concrete

Concrete grade / mix	Characteristic compressive strength (MPa)
M20	20
M25	25
M30	30
M40	40
Developed RPC mix	69.40

Table III shows that the developed RPC mix has a much higher compressive strength than conventional concrete grades. While normal concrete such as M20, M25, M30, and M40 typically covers the range used for ordinary structural work, the RPC mix reaches 69.40 MPa, placing it well above standard grades and making it suitable for more demanding applications.

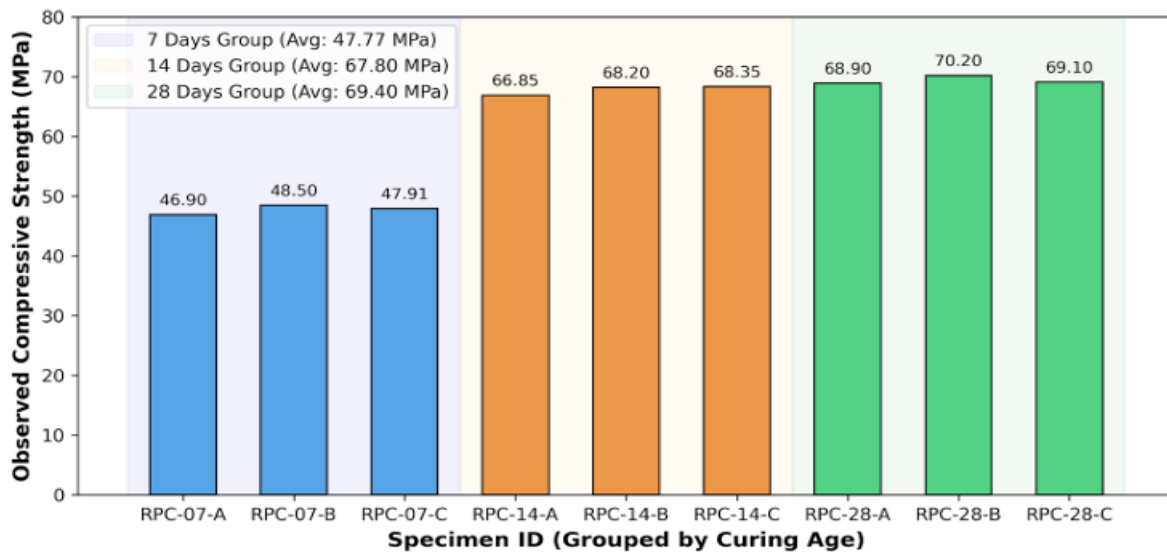


Fig 5.1 Compressive strength of RPC Specimen by curing age

VI. CONCLUSION

his experimental study successfully developed a high-strength, fibre-reinforced RPC-type concrete using OPC 53-grade cement, Rice Husk Ash, quartz powder, fine river sand, PCE superplasticizer, and micro steel fibres under standard laboratory conditions. The optimized mix achieved a 28-day average compressive strength of about 69.40 MPa, representing a substantial improvement over conventional structural concrete and confirming its classification as high-performance concrete.

The results demonstrated rapid early-age strength development up to 14 days, driven by the combined hydration of cement and pozzolanic reaction of RHA, followed by a strength plateau due to ambient water curing and limited activation of quartz powder. Microstructural analysis indicates that RHA and quartz powder significantly refine the pore structure and enhance matrix density, while steel fibres provide effective crack-bridging and improve ductility and post-peak behaviour. However, the mix did not reach the ultra-high-performance RPC range of 100–150 MPa due to the absence of elevated-temperature curing, the need for slightly higher water content to maintain workability, and insufficient compaction energy to fully eliminate entrapped air.

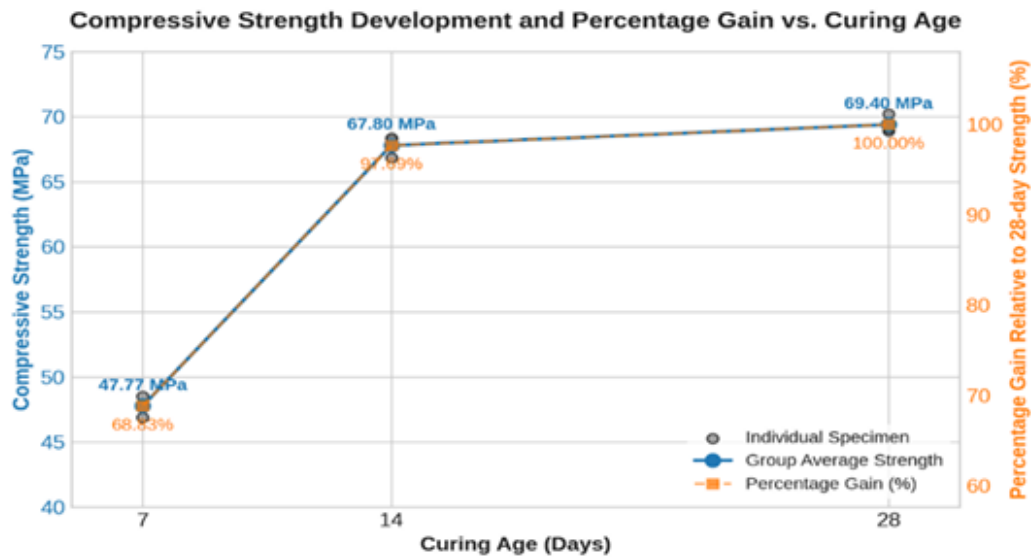


Fig 6.1: Compression strength development and percentage gain vs curing age

From a practical perspective, the developed composite is promising for precast infrastructure, heavily loaded bridge elements, high-rise columns, and marine or aggressive exposure conditions, where high strength and improved durability are desired beyond conventional concrete capabilities. Future work should focus on implementing steam or autoclave curing, optimizing superplasticizer dosage to reduce the effective water-binder ratio, and adopting advanced compaction techniques to minimize residual porosity and further push the mix towards true ultra-high-performance RPC behaviour.

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