

Research Article

Mechanical Performance and Reliability Assessment of Nanosilica-Modified High-Strength Concrete Beams

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Abstract

The growing demand for high-performance and durable construction materials has led to increasing interest in nanotechnology applications in concrete. This study investigates the mechanical properties, microstructural behavior, and structural reliability of high-strength concrete beams (HSCBs) incorporating nanosilica as a partial cement replacement. Experimental investigations were conducted on concrete mixes containing 0%, 3%, 5%, and 7% nanosilica by weight of cement. Material characterization included sieve analysis, specific gravity, water absorption, and density tests for aggregates, while nanosilica was evaluated using SEM/EDX and FTIR to examine its morphology and chemical interactions. Compressive strength tests were performed at 7, 14, 21, and 35 days, and flexural strength tests were conducted on reinforced concrete beams. Results showed significant improvements in both compressive and flexural strengths with nanosilica incorporation, with the optimum performance observed at 5% replacement, achieving up to 18% higher compressive strength than the control mix. Microstructural analysis confirmed enhanced formation of calcium silicate hydrate (C–S–H) gel and pore refinement due to nanosilica's pozzolanic reactivity and filler effect. Furthermore, structural performance was evaluated using both deterministic design methods and reliability-based analysis (FORM), demonstrating that nanosilica-modified beams achieved higher reliability indices and reduced probabilities of failure. The study concludes that controlled incorporation of nanosilica significantly enhances the strength, durability potential, and structural safety of high-strength concrete beams.

Keywords

Nanosilica, High-strength Concrete, Compressive Strength, Flexural Strength, Microstructure, Reliability Analysis, Form, Pozzolanic Reaction, Structural Safety

1. Introduction

Modern concrete is a highly advanced composite material that is continually being refined and [4]. Despite these advancements, the fundamental components of traditional ordinary Portland cement (OPC) are concrete—namely fine and coarse aggregates, cement, and water remain unchanged. To alter the

properties of OPC concrete, various chemical admixtures such as superplasticizers, water reducers, and air entrainers can be incorporated [2]. Additionally, there has been a growing trend in utilizing pozzolanic materials like fly ash, granulated blast-furnace slag, and silica fume. Hydraulic cements are generally

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Received: 15 June 2026; Accepted: 26 June 2026; Published: 17 July 2026



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categorized into two main types: General Purpose (GP) cements, which include ordinary Portland cements and blended cements, and special purpose cements. GP cement is typically used in standard concrete applications where specific characteristics, such as sulfate resistance or high early strength, are not required. The most common fine and coarse aggregates used in concrete production include natural gravels, sands, and crushed stones. In urban areas, crushed granite and river sands are frequently utilized as aggregates.

While fine and coarse aggregates primarily act as inert fillers in the concrete matrix, their petrographical, physical, and mechanical properties can greatly influence both the plastic and hardened characteristics of concrete [5]. Key aggregate properties include particle size distribution, shape, porosity, and potential reactivity with cement. Notably, the surface texture of aggregates can significantly affect concrete strength; for instance, cubically shaped crushed stones with rough surfaces tend to yield stronger concrete compared to smoother uncrushed gravel, as they enhance the bond between the aggregate and cement paste [18]. Fine aggregate constitutes about 30% of the total volume of conventional concrete, and its quality is crucial for the overall properties of the concrete mix [7]. The optimal amount of fine aggregate depends on various factors, including the grading of the aggregate, cement content, and the intended use of the concrete. River, pit, and quarry sands are commonly used sources for fine aggregate, which typically contain a high silica content that promotes better bonding with cement, resulting in more durable concrete [1].

The particle size distribution of fine aggregate is often represented by the fineness modulus (FM), calculated from the cumulative percentages retained on standard sieves. Although the FM provides a basic overview of aggregate grading, it can be useful for assessing uniformity in grading when minor variations are expected. The ideal FM for fine aggregate should range from 2.3 to 3.2, with lower values indicating finer grading and higher values indicating coarser grading [17]. Fine aggregates with an FM of 2.5 or lower may lead to concrete with poor workability and lower compressive strength, while those with an FM between 2.75 and 3.2 tend to produce stronger and more durable concrete.

Using substandard fine aggregate can hinder the setting process, increase bleeding, and result in poor workability, ultimately leading to concrete that is porous, highly permeable, and less durable [2].

As the concrete industry in Nigeria evolves, the emphasis on using alternative aggregates and materials is becoming crucial. The rising costs of transportation and the environmental impact of waste underscore the need for a shift towards more sustainable practices. Concrete manufacturers are encouraged to explore alternative materials, ensuring that the final products meet the necessary specifications while contributing positively to environmental goals. Concrete waste, categorized as construction and demolition (C&D) waste, is produced during

the construction of new urban infrastructure or the modification of existing structures, such as transportation systems, communication networks, and buildings [3].

As urbanization accelerates due to the growing global population, the generation of C&D waste also increases. This situation highlights the need for effective management of materials found in urban infrastructure, including concrete, steel, and bricks, to support future growth and meet rising construction material demands. In developed nations, there is a growing societal expectation for government agencies and industries to seek alternative materials and minimize waste to promote ecologically sustainable development [15]. A 2000 report by the US Department of Transportation on recycled materials in European highway environments found that many countries in the European Union, particularly Denmark, the Netherlands, and Germany, have well-established practices for recycling and reusing C&D waste [16].

The report notes that in the Netherlands, for example, 1.2 million tonnes of recycled asphalt rubble is utilized as concrete aggregate, and significant amounts of bottom ash are incorporated as lightweight aggregate in concrete block production. Furthermore, it is noteworthy that 100% of fly ash from municipal waste incineration, as well as GGBF slag and electric coal fly ash, is repurposed in cement production or in concrete as supplementary cementitious materials. Almost all building and demolition waste is also recycled, with 2 million tonnes (about 20% of all concrete waste) being used as concrete aggregate [11-14]. Numerous examples of the reuse and recycling of concrete waste in new infrastructure can be found. In Victoria, awareness of the social and environmental impacts of C&D waste has grown since 1986, leading to an increase in concrete waste recycling. Currently, over 50% of concrete waste is recycled, with 0.7 million tonnes reported as recycled in the 1997/98 period. Most recycled concrete aggregate is utilized in road construction as a substitute for natural aggregate, primarily in sub-base layers.

2. Materials and Methods

2.1. Materials

In order to accomplish this research's objectives, materials such as Cement (Ordinary Portland Cement), Coarse Aggregate (Granite), Fine Aggregate (Sharp Sand), Water Reinforcement were sourced and carefully selected from different location within Lagos State while Nano-silica was purchased from ENAL Marine & Environmental Services Ltd. Lagos.

2.1.1. Cement

Ordinary Portland cement from Dangote 3X portland cement brand for high strength concrete will be used as the binder, which is commonly sold in the various retail outlets. Both physical and chemical properties test were carried out on the Cement in accordance with [6] (Figure 1).



Figure 1. Dangote 3X Cement.

2.1.2. B. Aggregates

For the purposed of this research work, the fine aggregate (sharp sand) and the coarse aggregate (12mm.-sized granite) will be obtained from various construction site within Lagos. The tests that will be carried out include, specific gravity, particle size distribution using sieve analysis, water absorption.



Figure 2. Sand and Granite.

2.1.3. Water

The water used was clean and in accordance with the British Standards Specifications. The water was obtained from Yabatech main campus, Yaba.

2.1.4. Nano-Silica



Figure 3. Jute Fibre Used.

2.2. Method

Yaba College of Technology, civil engineering department concrete laboratory was used for all the experiment conducted on the materials including the crushing of the cubes and flexural test. While chemical anaysis of the nano silica was done at the Yaba College of Technology Central Laboratory. The test carried out were based on the major concrete constituent such as cement and aggregate and trial mix was also conducted to determent the mix ratio for this research work.

2.2.1. Physical Properties of Materials

(i). Specific Gravity Test

Specific gravity is the ratio of the mass of a substance to the mass of a reference substance. It was determined through laboratory experiment using the Le-Chatelier Flask method with the following apparatus and materials (Kerosene, Ordinary Portland cement, Weighing balance and Le-Chatelier flask).

$$\text{Specific gravity} = \frac{w_2 - w_1}{(w_4 - w_1) - (w_3 - w_1)} \quad (1)$$

(ii). Sieve Analysis Test

This test is carried out in accordance with ASTM D6913: Standard test method for particle-size distribution (gradation).

Find coefficient of uniformity and coefficient of curvature.

$$Cu = \frac{D_{60}}{D_{10}} \quad (2)$$

$$Cc = (D_{30})^2 / (D_{60} \times D_{10}) \quad (3)$$

(iii). Water Absorption Test

The water absorption was also conducted based on BS Standard.

2.2.2. Chemical Properties Test

Scanning Electron Microscopy / Energy Dispersive X-ray Spectroscopy (SEM/EDX) Test

SEM coupled with EDX was used to study the surface morphology and elemental composition of nanosilica-blended HSCB. Small fragments of hardened concrete specimens were taken after 28 days of curing. The samples were oven-dried at $105 \pm 5^\circ\text{C}$, mounted on aluminum stubs, and coated with a thin layer of gold using a sputter coater to ensure electrical conductivity. Microstructural analysis was carried out using a Scanning Electron Microscope (SEM) operated at an accelerating voltage of 15–20 kV. High-resolution images were obtained to observe the morphology, particle distribution, and interfacial transition zone (ITZ) between cement paste and aggregates. Simultaneously, Energy Dispersive X-ray Spectroscopy (EDX) was performed to obtain the elemental composition of selected regions. This provided semi-quantitative data on the presence of silicon (Si),

calcium (Ca), oxygen (O), and other trace elements. The SEM images were used to evaluate the pore structure, density, and dispersion of nanosilica particles, while EDX spectra confirmed the enhanced silica and calcium silicate hydrate (C–S–H) formation due to nanosilica incorporation.

2.2.3. Mechanical Properties Test

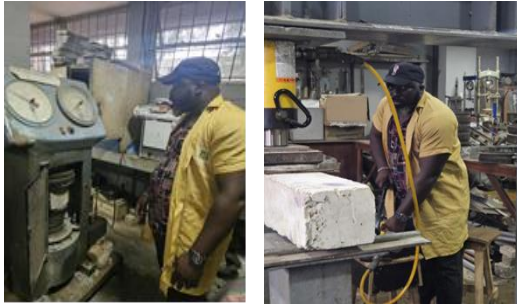


Figure 4. Compressive and Flexural Strength Tests Set-up.

The compressive strength test of the hardened concrete was determined after the required curing days of 7, 14, 21 and 35 days without replacement and with nano silica replacement at 3%, 5% and 7% using the Compressive testing machine (Budenberg) at the concrete laboratory of Yaba College of Technology in accordance with [6]. Total numbers of cubes cast were 64 cubes.

2.2.4. Deterministic-Based Design

The structural design of High Strength Concrete Beams (HSCBs) with blended nanosilica was assessed using deterministic approach. While deterministic design evaluates safety using fixed characteristic values and safety factors, reliability-based design incorporates the probability of failure, uncertainties in material properties, load effects, and resistance models, thereby providing a more realistic measure of structural performance. The deterministic design was carried out using a structural plan (Figure 5) with the following equations based on [6, 8-10]:

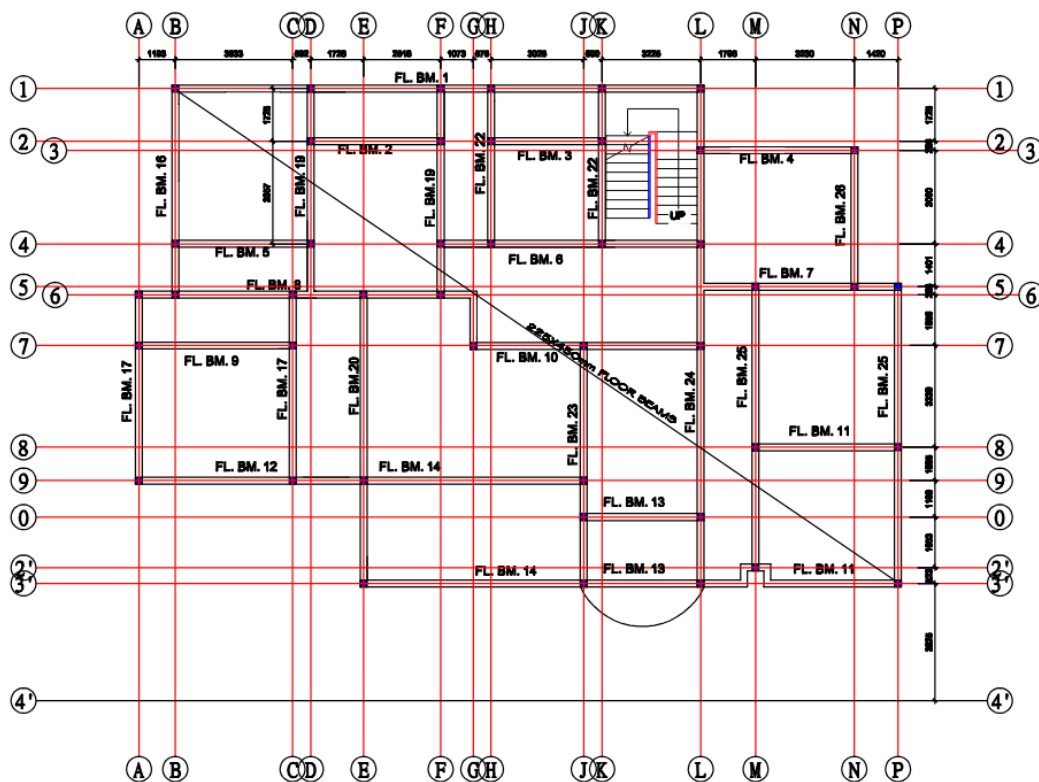


Figure 5. Floor Plan of an office Complex.

$$\text{Design load, D.L} = 1.4 G_K \quad (4)$$

$$\text{Slab load on beam along shorter span, } = 1/3 \omega l_x \quad (5)$$

$$\text{Slab load on beam along long span, } = 1/2 \omega l_x \left(1 - \frac{1}{3} k^2\right) \quad (6)$$

$$\text{Effective depth, } d = h - \text{cover} - 1/2\phi - \text{links} \quad (7)$$

Shear stress, $v = V/1.18bd$ for 5% optimum replacement of Nanosilica

$$v = V/1.18bd \quad (8)$$

$$k = M/(bf \ d^2 \ f_{cu}) \quad (9)$$

$$I_a = 0.5 + \sqrt{(0.25 - k/0.9)} \quad (10)$$

$$A_s = M/(0.95f_y \ z) \quad (11)$$

3. Results and Discussion

3.1. Physical Property Results

3.1.1. Specific Gravity Result

Specific gravity of aggregates is considered as an indication of strength. The specific gravity of fine aggregates normally used in construction ranges from about 2.5-3.0, with an average value of about 2.68. From Table 1 the average specific gravity value for fine aggregates lies within the accepted range with a value of 2.62.

Table 1. Specific Gravity Result for Fine Aggregate.

SAMPLES		A	B
W1	Weight of Density Bottle	600	598
W2	Weight of Bottle + Soil	1763	1643
W3	Weight of Bottle + Soil + Water	2591	2518
W4	Weight of Bottle + Water	1882	1870
Gs (Specific Gravity)		2.6	2.63
Average Specific Gravity Value		2.62	

Table 2. Specific Gravity Result for Coarse Aggregate.

SAMPLES		A	B
W1	Weight of Density Bottle	820	854
W2	Weight of Bottle + Sample	2800	2884
W3	Weight of Bottle + Sample + Water	3687	3733
W4	Weight of Bottle + Water	2453	2478
Gs (Specific Gravity)		2.7	2.62
Average Specific Gravity Value		2.66	

Specific gravity of aggregates is considered as an indication of strength. Materials having higher specific gravity is generally considered having higher strength. The specific gravity of aggregates normally used in construction ranges from about 2.5-3.0, with an average value of about 2.68. From Table 2 the average specific gravity value for coarse aggregates lies within the accepted range with a value of 2.66.

3.1.2. Water Absorption Result (Nano Silica)

Figure 6 shows the porosity and water absorption of nano-silica. Water absorption decreases as nano-silica content increases likewise the porosity.

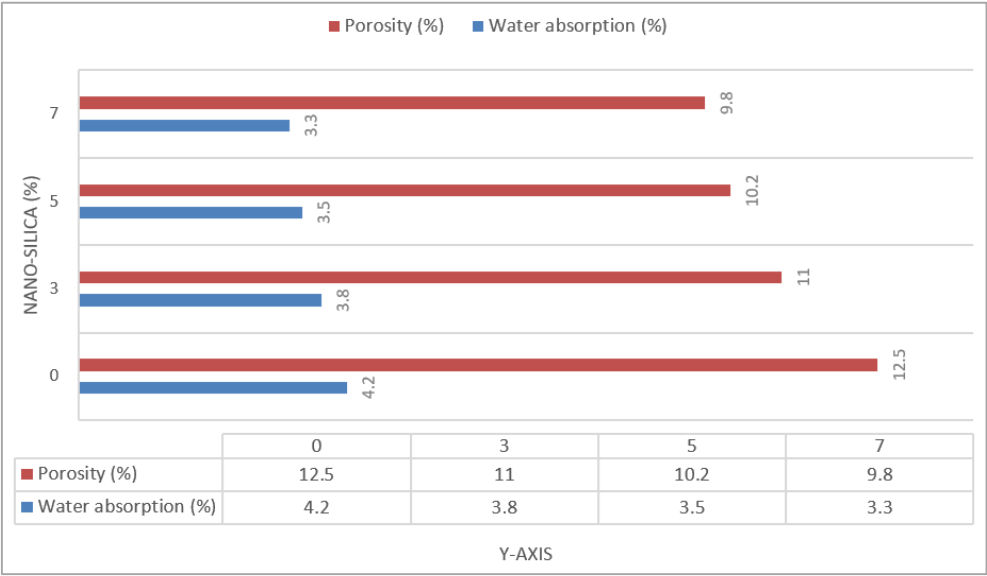


Figure 6. Water Absorption and Porosity of Nano-Silica Content.

Water absorption values showed a significant difference between fine aggregates (21%) and coarse aggregates (1.66%), suggesting that the fine aggregates have higher porosity and greater potential to retain moisture, which may influence the water-to-cement ratio and workability of the mix.

3.1.3. Density Result

The bulk density of aggregate is the weight of aggregate needed to fill a unit volume of the container. The approximate value of bulk density for aggregate usually used for normal weight concrete varies between 1200-1750 kg/m³. The used aggregate for this research work falls in between this range value which means the aggregates (fine & coarse) are desirable.

Table 3. Density Result.

SAMPLES	A(g)
Bulk Density (Kg/m ³) Sand	1311
Bulk Density (Kg/m ³) Granite	1406

3.1.4. Sieve Analysis Result

The values of Cu and Cc are used to classify whether the soil is well graded or not. Sand is considered well graded, if Cu is greater than 6 and Cc is between 1 and 3. From Figure 7 uniform of coefficient (Cu) is 3.5 while Coefficient of curvature is 1.28 which indicates that the soil is uniformly graded.

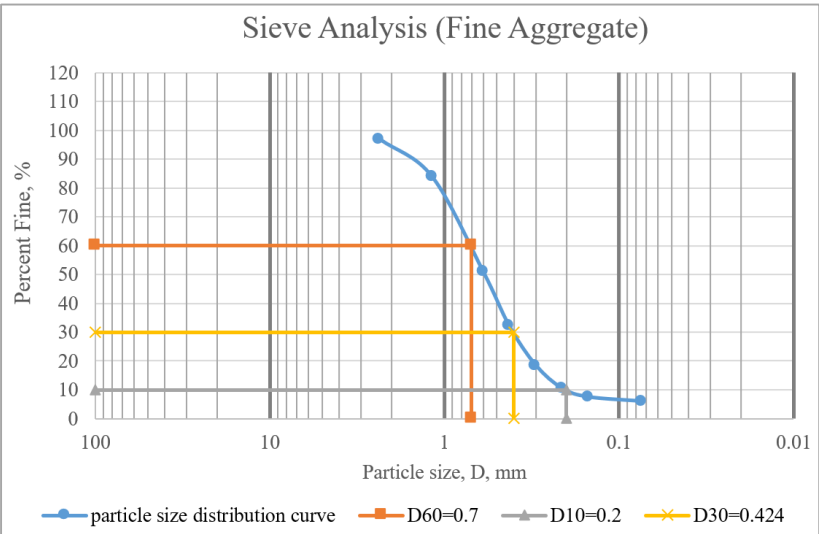


Figure 7. Sieve Analysis Result.

Sieve analysis results showed that fine aggregates exhibited a coefficient of uniformity (Cu) of 3.5 and a coefficient of curvature (Cc) of 1.28, classifying them as uniformly graded. Coarse aggregates, however, showed Cu = 1.43 and Cc = 1.0, indicating a single-sized distribution, which is less favorable for achieving dense packing unless combined with finer particles. According to Mehta and Monteiro (2014), “aggregates with well-graded particle size distribution reduce void content and improve concrete strength and durability,” which aligns with the importance of blending these materials appropriately. Overall, the physical properties obtained in this study are within standard specifications and comparable to values reported in previous studies, suggesting their suitability for use in durable and high-performance concrete structures.

3.2. Chemical Properties Results

The materials characterization obtained in this study aligns closely with prior nanosilica-in-concrete literature and supports the mix design and reliability modeling assumptions. The fine aggregate grading (FM = 2.73) and high sand equivalent (84%) are typical of well-graded river sands used in high-performance mixes and comparable to values reported in mix designs targeting dense packing and low paste demand. The measured specific gravities (2.64 fine; 2.71 coarse) and low moisture contents (1.2% and 0.8%) fall within customary ranges for granitic systems and are consistent with datasets used in deterministic/variability studies on high-strength concrete (HSC).

Table 4. Material Characterization Result.

Property	Fine Aggregate	Coarse Aggregate	Nanosilica
Fineness Modulus (FM)	2.73	—	—
Max. Aggregate Size (mm)	—	20	—
Sand Equivalent (%)	84	—	—
Specific Gravity (Gs)	2.64	2.71	—
Moisture Content (%)	1.2	0.8	—
SiO ₂ (wt.%)	—	—	94.7
Al ₂ O ₃ (wt.%)	—	—	1.2
Fe ₂ O ₃ (wt.%)	—	—	0.8
CaO (wt.%)	—	—	1.6
MgO (wt.%)	—	—	0.5
Particle Size (nm)	—	—	50–80 (d ₅₀ = 65)
BET Surface Area (m ² /g)	—	—	178
Morphology (SEM)	—	—	Spherical/irregular, dispersed in C–S–H

Critically, the nanosilica chemistry (SiO₂ ≈ 94.7 wt.% with minor Al₂O₃, Fe₂O₃, CaO, MgO) confirms a high-purity amorphous silica source comparable to materials reported commercial nanosilica purities >90–99 wt.% and BET surface areas commonly between ~150–300 m²/g; our BET value (178 m²/g) and median size (d₅₀ ≈ 65 nm) sit squarely in that bandwidth. The observed SEM features—spherical-to-irregular particles, occasional agglomerates that disperse adequately under proper mixing, and a markedly denser C–S–H gel at 28 days—mirror microstructural signatures repeatedly documented for nanosilica-modified pastes, including accelerated portlandite

consumption, C–S–H nucleation densification, and pore refinement. Several studies have also linked such microstructural changes to macroscopic performance gains (higher early/28-day strengths, reduced permeability, and improved ITZ density), mechanisms our micrographs qualitatively corroborate.

3.3. Mechanical Properties Results

Compressive and Flexural Strength Test Results

All nanosilica mixes achieved higher early strength than the control, especially at 7 and 14 days. The 5% replacement (NS-

5) consistently showed the highest compressive strength across all curing ages, indicating an optimal balance of filler effect, pozzolanic activity, and workability. The 7% replacement (NS-7) still improved strength compared to the control

but showed slightly lower values than 5%, likely due to reduced workability and particle agglomeration at higher dosages. By 35 days, NS-5 achieved $\sim 63.5 \text{ N/mm}^2$, which is about 18% higher than the control. Table 5 shows the compressive strength test result.

Table 5. Compressive Strength Result.

Mix ID	% Nanosilica	7 Days (N/mm ²)	14 Days (N/mm ²)	21 Days (N/mm ²)	35 Days (N/mm ²)
Control (C0)	0%	32.5	41.2	47.6	53.8
NS-3	3%	36.8	45.5	51.4	59.2
NS-5	5%	38.6	48.9	55.7	63.5
NS-7	7%	34.7	44.0	50.3	57.0

Flexural strength results (Table 6) followed a similar pattern. The control mix (0% nanosilica) achieved an average of 5.8 MPa at 21 days, while the 3%, 5%, and 7% nanosilica mixes attained 6.4, 7.1, and 6.9 MPa, respectively. The 5% nanosilica mix (NS-5) exhibited the highest strength gain, showing about 22% improvement compared to the control. This enhancement can be attributed to the densification of the microstructure and improved interfacial bonding between the cement paste and aggregates induced by nanosilica. However, at 7% replacement (NS-7), flexural strength decreased slightly compared to the 5% mix, indicating that excessive nanosilica

may increase water demand, reduce workability, and promote particle agglomeration, thereby limiting performance. The control mix (0% nanosilica) achieved an average flexural strength of 5.8 MPa at 21 days. The addition of nanosilica improved flexural strength, with 5% replacement (NS-5) showing the highest strength gain (+22%), likely due to enhanced microstructure densification and improved bonding. At 7% replacement (NS-7), strength decreased slightly compared to the 5% mix, suggesting that excessive nanosilica may increase water demand, reduce workability, and lead to particle agglomeration, thereby affecting performance.

Table 6. Flexural Strength.

Mix ID	% Nanosilica Replacement	Average Flexural Strength (MPa)	% Increase Compared to Control
Control	0% (No Nanosilica)	5.8	—
NS-3	3%	6.5	+12%
NS-5	5%	7.1	+22%
NS-7	7%	6.7	+16%

From a standards perspective, the mechanical performance of these samples meets the requirements for non-structural ceiling applications. According to [6], ceiling panels in non-load-bearing environments should resist minor bending and maintain integrity under service conditions. Sample A clearly satisfies these criteria, offering the highest load-bearing capacity and flexibility. Sample B, while less strong, presents a sustainable alternative with good crack resistance and reduced deflection, ideal for settings where weight and resilience are more critical than peak strength.

3.4. Deterministic Approach Results

Loading of Beams:

Slab load = $0.15 \times 24 = 3.6 \text{ kN/m}^2$

Partition = 1.0 kN/m^2

Finishes = 1.2 kN/m^2

5.8 kN/m^2

$D.L = 1.4 G_K + 1.6 Q_K = 1.4 \times 5.8 + 1.6 \times 3 = 12.92 \text{ kN/m}^2$
 $= 13 \text{ kN/m}^2$

Beam	17.12kN/m
Self wt. of Beam = $0.225 \times 0.6 \times 24 = 3.24\text{kN/m}$	Total load on 1D-F = $17.12 + 21 = 38 \text{ kN/m}$
Finishes = 1.2kN/m	Load on 1F-H = $1/3 \omega l_x = 1/3 \times 13 \times 1.775 =$
Wall load = $3.47 \times 3 = 10.4\text{kN/m}$	7.69kN/m
14.85kN/m	Total load on 1F-H = $7.69 + 21 = 29 \text{ kN/m}$
Design load, D.L = $1.4 G_k$	Point Load on F-H
= $1.4 \times 14.85 = 20.75\text{kN/m}$	Wall load = $3.47 \times 3 \times 1.725 \times 1.4 = 25\text{kN}$
Slab load on beam along shorter span,	Maximum Bending Moment (Supports) = 54.9kNm
= $1/3 \omega l_x$	Maximum Bending Moment (Span) = 49.4kNm
Slab load on beam along long span,	Maximum Shear = 89kN
= $1/2 \omega l_x (1 - 1/3 k^2)$	Effective depth, $d = h - \text{cover} - 1/2\phi - \text{links} =$
Spans ratio, $k = L_y/L_x$	$600 - 25 - 8 - 10 = 557\text{mm}$
Beam 1D-H (FL. BM. 1)	Shear stress, $v = V/1.18bd$ for 5% optimum replacement
Load on 1D-F = $1/3 \omega l_x = 1/3 \times 13 \times 3.955 =$	of Nanosilica

$$v = V/1.18bd = 89000/(1.18 \times 502 \times 557) = 0.27\text{N/mm}^2$$

Assuming and L-Beam:

$$\text{Breadth of flange (1D-F)} = b_w + 0.1 \times 0.7 \times l_x = 225 + 0.1 \times 0.7 \times 3955 = 501.9\text{mm}$$

$$\text{Breadth of flange (1F-H)} = b_w + 0.1 \times 0.7 \times l_x = 225 + 0.1 \times 0.7 \times 1755 = 347.9\text{mm}$$

Design for Tension reinforcement

$$k = M/(b_f d^2 f_{cu}) = (54.9 \times 10^6)/(501.9 \times 557^2 \times 25) = 0.0141$$

$$I_a = 0.5 + \sqrt{(0.25 - k/0.9)} = 0.95$$

$$z = I_a d = 0.95 \times 557 = 529.15 \text{ mm}$$

$$A_s = M/(0.95 f_y z) = (54.9 \times 10^6)/(0.95 \times 410 \times 529.15) = 266 \text{ mm}^2$$

$$\text{Provide } 2Y1601 \text{ TOP } (402 \text{ mm}^2)$$

Design for Compression reinforcement

$$k = M/(b_f d^2 f_{cu}) = (49.4 \times 10^6)/(347.9 \times 557^2 \times 25) = 0.0183$$

$$I_a = 0.5 + \sqrt{(0.25 - k/0.9)} = 0.95$$

$$z = I_a d = 0.95 \times 557 = 529.2 \text{ mm}$$

$$A_s = M/(0.95 f_y z) = (49.4 \times 10^6)/(0.95 \times 410 \times 529.15) = 240 \text{ mm}^2$$

$$\text{Provide } 2Y1602 \text{ BTM } (402 \text{ mm}^2)$$

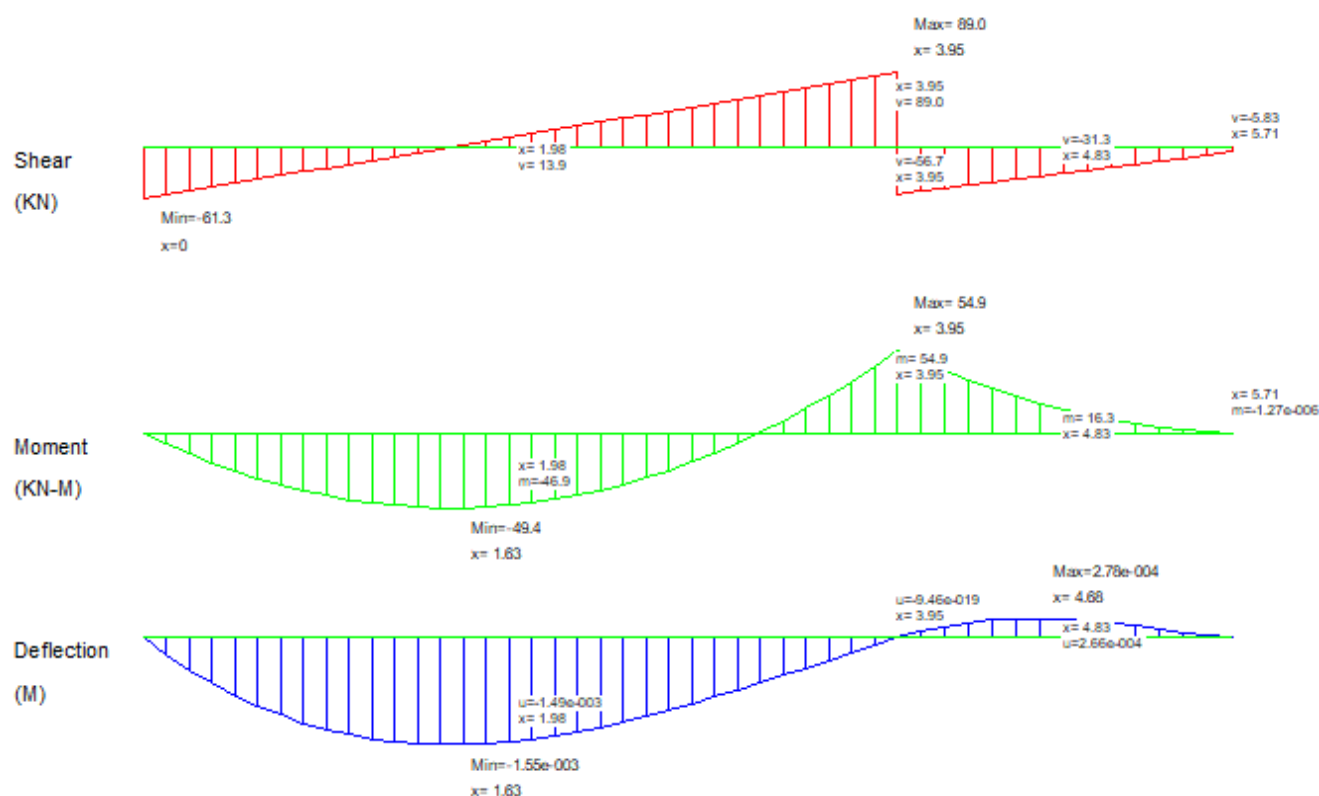


Figure 8. Deflection Result.

4. Conclusion

This study evaluated the influence of nanosilica on the mechanical performance, microstructural characteristics, and structural reliability of high-strength concrete beams. Experimental results confirmed that nanosilica significantly enhances both compressive and flexural strengths, particularly at early curing ages, due to its high surface area and pozzolanic reactivity. Among the investigated dosages, 5% nanosilica replacement was found to be optimal, providing the highest strength gains and improved microstructural densification without adverse effects such as particle agglomeration or reduced workability observed at higher percentages. Microstructural investigations using FTIR and SEM/EDX verified increased C–S–H formation, reduced porosity, and a denser interfacial transition zone, explaining the observed improvements in mechanical properties. From a structural design perspective, reliability-based analysis demonstrated that beams incorporating nanosilica exhibit higher reliability indices and lower probabilities of failure compared to conventional concrete beams, indicating improved structural safety under uncertainty in material properties and loading. Overall, nanosilica is shown to be an effective nano-modifier for producing

stronger and more reliable high-strength concrete. Its appropriate use can contribute to more durable, efficient, and safer concrete structures, particularly in applications where high performance and long-term reliability are critical.

Abbreviations

NS	Nanosilica
HSC	High-strength Concrete
Cu	Coefficient of Uniformity
Cc	Coefficient of Curvature
FM	Fineness Modulus

Author Contributions

Ooye Steeve Tob: Data curation, Methodology
John Wasiu: Supervision
Ibrahim Abdulrazaq Olayinka: Validation
Osegbowa Douglas Enoguan: Visualization

Conflicts of Interest

The author(s) declare that there is no conflict of interest regarding the publication of this manuscript.

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