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# **A Study on the Geotechnical Behaviour of Bentonite-Nano Silica Mixtures**

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**ABSTRACT:** Bentonite, a weak and soft clay prone to large settlement and low shear strength, poses challenges for civil engineering projects. This study investigates the use of nano silica, varied from 0.2% to 1% by dry weight, to enhance bentonite's geotechnical properties. Results show that the liquid limit, plastic limit, dry unit weight, and optimum moisture content consistently increase with higher nano silica content. Unconfined compressive strength (UCS) and split tensile strength improve up to an optimum dosage, after which they decline. Strength gains were also proportional to curing time. A higher rate of increase in plastic limit compared to liquid limit led to a reduced plasticity index. After 28 days, UCS and tensile strength increased by 88.13% and 56.56%, respectively. Nano silica also reduced settlement by 65% at 0.8% content, while compression and recompression indices decreased, and pre-consolidation pressure increased. Nano silica modifies bentonite at the nano and micro levels, enhancing gradation and forming cementitious gels that strengthen particle bonds. These improvements make construction over bentonite-rich soils more feasible and promote sustainable use of the material.

**KEYWORDS:** Nano silica, bentonite, consistency limits, unconfined compressive strength, tensile strength, Settlement

## **I. INTRODUCTION**

Bentonite is an expansive soil with low shear strength and high shrink-swell potential due to montmorillonite mineral content, causing structural damage from differential settlement. Its geotechnical limitations hinder construction of foundations, embankments, pavements, and hydraulic structures, necessitating modification. Past stabilizers like lime, cement, fly ash, and phosphogypsum have improved bentonite properties; for example, fly ash reduced plasticity index (Cokca 2001), and cement with rice husk ash increased optimum moisture content (Basha et al. 2003). Nano additives have recently emerged as superior soil modifiers due to their high reactivity and environmental sustainability compared to traditional methods like cement, which contribute heavily to pollution. Nano silica, being non-toxic and naturally occurring, offers improved penetration, reduced environmental risk, and enhanced soil properties at the nano and micro levels. Prior studies have shown nano silica increases dry unit weight, reduces collapse potential, and improves compressive strength by forming additional cementitious gels (Choobbasti et al. 2015; Ghasabkolaei et al. 2016). Nano silica also improves drilling mud by increasing yield stress and reducing fluid loss (Vipulanandan and Mohammed 2020b). In fine-grained soils like bentonite, nano silica's high specific surface area enhances electrostatic interactions and particle bonding, leading to improved geotechnical behavior. This study aims to modify bentonite's properties using nano silica. Laboratory tests, including Atterberg limits, compaction, unconfined compressive strength, split tensile strength, and consolidation, were conducted following standard codes. The nano silica's filling effect, particle dispersion, and surface reactivity are leveraged to enhance bentonite's physical, chemical, and microstructural characteristics, revealing promising results for field applications and addressing sustainability concerns.

## **II. LITERATURE SURVEY**

**Taha (2009)** reported that mixing nano soil particles with three varieties of natural clay minerals led to an increase in their liquid and plastic limits. Similarly, **Moharram et al. (2016)** conducted liquid and plastic limit tests on clay mixed with nano silica and nano kaolin and observed an increase in these properties. **Malik et al. (2019)** also reported an enhancement in the liquid and plastic limit of medium compressibility clay after adding nano silica. However, **Ahmadi**



and Shafiee (2019) found a decrease in the liquid limit and plasticity index when nano and micro silica were used as admixtures in clay.

**Majeed and Taha (2012)** conducted compaction tests on low compressibility organic soils mixed with 0.001% and 0.002% nano CuO, nano MgO, and nano clay. Changizi and Haddad (2016) reported increases in dry unit weight and optimum moisture content by 1.05 to 1.2 times in low compressibility clay mixed with varying percentages of nano silica. In contrast, Taha, Govindasamy, and Alsharef (2019) observed an increase in dry unit weight with a reduction in optimum moisture content when silty clay was treated with nano lime and lime particles. Similarly, Mir and Reddy (2021) noticed increased dry unit weight and decreased optimum moisture content in low compressible silt after incorporating nano alumina.

**Changizi and Haddad (2015)** found improved unconfined compressive strength behavior in clay after admixing nano silica and recycled glass fiber. Further, Changizi and Haddad (2017) highlighted enhanced peak and residual compressive strengths when nano clay and glass fiber were added to clay. Meng et al. (2017) studied the effect of nano calcium carbonate and cement on marine foundation soils and concluded that simultaneous addition improved compressive strength better than cement alone. Yousefi, Jahanian, and Azadi (2020) similarly reported increased compressive strength when clay was stabilized with cement and nano cement. Improved tensile strength was also recorded by Taha et al. (2018) for bentonite mixed with nano carbon, and by Mahmoudian et al. (2020) for collapsible soils mixed with nano and micro alumina.

**Cheng et al. (2020)** performed consolidation tests on clay mixed with nano bentonite, showing reductions in void ratio and compression coefficient. Karumanchi et al. (2020) investigated soft clay mixed with nano clay and found decreased coefficient of consolidation. Mahmood et al. (2021) similarly observed reductions in void ratio, coefficient of consolidation, and coefficient of volume compressibility in soft clay stabilized with graphene oxide. From the review of existing literature, it is evident that most studies have focused on low compressibility clays mixed with various nano additives, but no significant research has yet been reported on the geotechnical behavior of bentonite mixed with nano silica.

### III. METHODOLOGY

#### 1. Materials Procurement and Characterization

Nano silica was sourced from Ad Nano Technologies, Karnataka, India, and bentonite from Sachdeva Traders, Jalandhar, India (Fig. 1a, 1b). The chemical compositions, as provided by the manufacturers, indicated high silicon dioxide content in both materials. Physical properties of nano silica are presented in Table 2. Specific gravities of bentonite and nano silica were determined as 2.25 and 1.67 respectively using the density bottle method (IS-2720-Part-III, 1980). Bentonite's maximum dry unit weight and optimum moisture content were found to be 11.57 kN/m<sup>3</sup> and 45.87%.



**Fig. 1 a) Bentonite b) nano silica**

## 2. Microstructural and Particle Size Analysis

Scanning Electron Microscopy (SEM) images for bentonite and nano silica are shown in Fig. 2a and 2b. Particle size distributions were assessed using a Zeta Sizer, with curves shown in Fig. 3a and 3b. The average particle size was 1638.6 nm for bentonite and 28.22 nm for nano silica, highlighting the nanoscale nature of the silica additive.

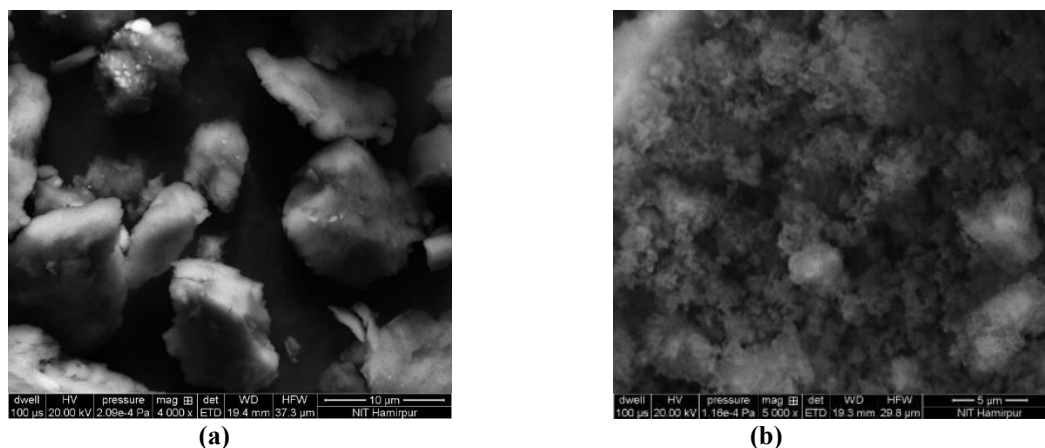


Fig. 2 SEM image of a) bentonite b) nano silica

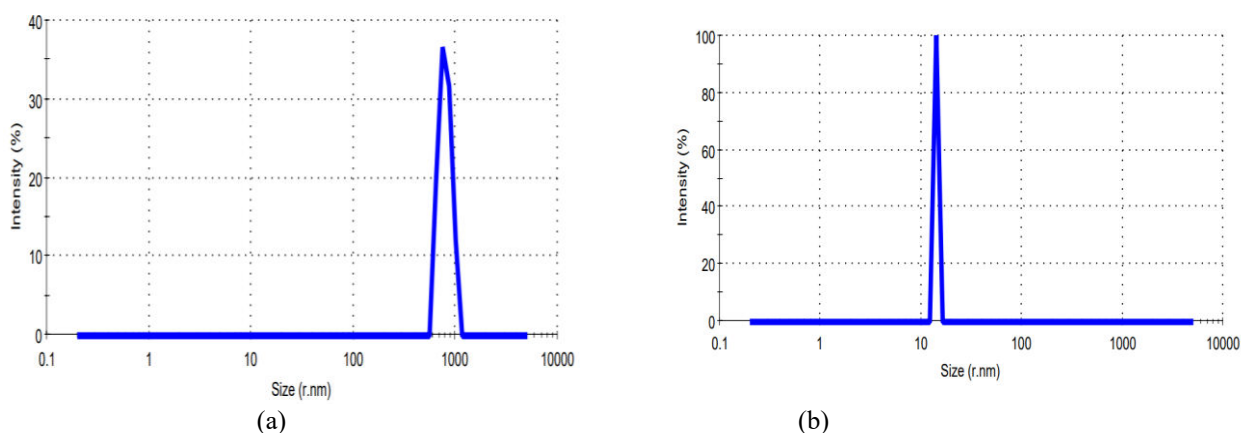


Fig.3 Particle size distribution with zeta sizer (a) bentonite b) nano silica

## 3. Liquid and Plastic Limit Determination

Liquid and plastic limits of nano silica-treated bentonite were determined per IS-2720-Part-V (1985). Bentonite passed through a 0.425 mm IS sieve was dry-mixed with varying nano silica dosages and distilled water. Liquid limit was measured via the cone penetration method, recording 20 mm penetration within 5 seconds. The plastic limit was determined using the thread rolling method, preparing 3 mm diameter threads until crumbling.

## 4. Standard Proctor Compaction Test

The influence of nano silica on maximum dry density (MDD) and optimum moisture content (OMC) was studied using the Standard Proctor Test as per IS-2720-Part-VII (1980). Dry bentonite mixed with 0% to 1% nano silica by weight was compacted in three layers inside a 1000 cc mould with 25 blows per layer using a standard hammer. The tests were repeated three times to obtain average compaction parameters.

## 5. Specimen Preparation for Strength Testing

A total of 72 specimens each for unconfined compressive strength (UCS) and split tensile strength were prepared. Dry mixtures of bentonite and nano silica were divided into three parts, moistened, and compacted statically into

cylindrical moulds (38 mm diameter, 76 mm height). Specimens were then extracted hydraulically and cured at  $25\pm 2^{\circ}\text{C}$  in airtight plastic bags (Fig. 4) for 7, 14, and 28 days.



Fig. 4 Curing of nano silica treated bentonite samples

#### **6. Unconfined Compressive Strength Testing**

After curing, UCS tests were conducted at a strain rate of 1.25 mm/min as per IS-2720-Part-X (1991). A proving ring of 5 kN capacity and a dial gauge (0.01 mm least count) were used to measure load and deformation. Three specimens for each mix were tested and averaged, ensuring the variation remained below 5%.

#### **7. Split Tensile Strength Testing**

Tensile strength was determined as per IS-5816 (1999) by loading the specimens diametrically in a compression machine. The procedure measured tensile strength and diametrical strain. For each mix, five specimens were tested, with results averaged from three selected specimens to ensure accuracy within 5% error.

#### **8. Consolidation Test**

Oedometer consolidation tests were conducted following IS-2720-Part-XV (1986) to determine compression index, recompression index, and pre-consolidation pressure. Mixtures were compacted into a consolidation ring (66.26 mm diameter, 19.4 mm height) in three layers, saturated under a 5 kPa load for five days. Dial gauges with a least count of 0.01 mm were used to measure compression. Specimens were coded according to nano silica content, e.g., "0.2NS" indicating 0.2% nano silica.

### **IV. CONCLUSION**

The study investigated the geotechnical behavior of bentonite mixed with varying nano silica contents. Liquid and plastic limits increased, but plasticity index reduced notably up to 0.8% nano silica due to higher water absorption and gel formation. Dry unit weight, optimum moisture content, unconfined compressive strength, and pre-consolidation pressure improved with nano silica addition, peaking at 0.8% content. Tensile strength showed maximum improvement at 0.6% dosage. Beyond these dosages, agglomeration effects reduced the gains. Overall, nano silica enhances the strength and reduces plasticity and compressibility of bentonite, facilitating better performance for embankment construction in bentonite-rich regions.

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