A Study On The Improvement Of Strength And Settlement Of Sandy Soils Using Marble Powder

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ABSTRACT
This study investigates the potential of marble powder, a byproduct of the marble cutting and polishing industry, as a sustainable and cost-effective additive for improving the geotechnical properties of sandy soils. Laboratory experiments were conducted to evaluate the effects of varying percentages of marble powder (0%, 5%, 10%, 15%, and 20% by dry weight of soil) on the strength and settlement behaviour of uniformly graded sand. Standard Proctor compaction, unconfined compressive strength (UCS), direct shear, and one-dimensional consolidation tests were performed to assess improvements in load-bearing capacity and compressibility. The results revealed that the inclusion of marble powder significantly enhanced the UCS and shear strength of sandy soils, with the optimum performance observed at 15% addition. Furthermore, settlement under loading was notably reduced due to the filler effect and pozzolanic reactivity of the marble powder, which contributed to denser packing and partial cementation of soil particles. The findings suggest that marble powder can serve as an effective and environmentally friendly stabilizer for sandy soils in geotechnical applications, particularly in subgrade and foundation works.

Keywords: *Sandy Soils, Marble powder, strength and settlement, direct shear, one-dimensional consolidation, compressibility, pozzolanic reactivity.*

1. INTRODUCTION

Soil stabilization is a critical process in geotechnical engineering aimed at improving the physical properties of soil to enhance its strength, bearing capacity, and resistance to deformation under load. Among various soil types, sandy soils are particularly challenging due to their low cohesion, poor shear strength, and tendency to undergo excessive settlement, especially under cyclic or dynamic loading conditions [1]. These issues are of great concern in construction activities involving shallow foundations, road subgrades, and embankments, where ground stability is a prerequisite for long-term performance.

Traditionally, chemical stabilizers such as cement and lime have been widely employed to enhance the engineering behaviour of soils. While effective, the production of these materials is energy-intensive and contributes significantly to greenhouse gas emissions, particularly carbon dioxide (CO_2) [2]. As a result, sustainable and environmentally friendly alternatives are being actively sought within the construction industry. The incorporation of industrial by-products and waste materials into soil stabilization techniques offers a promising route to minimize environmental degradation while addressing waste management challenges.Marble powder is one such waste material, primarily composed of calcium carbonate ($CaCO_3$), which is generated in vast quantities during marble processing activities such as cutting, grinding, and polishing. It is estimated that for every 1000 m^2 of marble slabs processed, approximately 250–400 kg of marble slurry or powder waste is produced [3]. In many developing countries, improper disposal of marble powder in open land or water bodies leads to pollution, land degradation, and deterioration of surface water quality [4]. From a geotechnical perspective, the fine particle size and mineralogical composition of marble powder can contribute to improved packing of soil grains and potential cementitious reactions under appropriate conditions [5]. Recent studies have explored the utility of marble powder in stabilizing clayey soils, with improvements noted in compaction, shear strength, and swelling characteristics [6]. However, its interaction with sandy soils-a granular system with fundamentally different behaviour-has not been studied as extensively. Sandy soils lack plasticity and have relatively high permeability, which means stabilizing them requires not only mechanical interlocking but also some degree of binding action among particles. Marble powder, with its high specific surface area and chemical activity, may fill voids between sand grains and promote particle bonding, thus enhancing strength and reducing settlement under load.

This research aims to systematically investigate the effect of marble powder on the strength and settlement characteristics of sandy soils through a comprehensive laboratory testing program. The study focuses on determining the optimum marble powder content that maximizes improvements in unconfined compressive strength (UCS), shear strength, and reduces consolidation settlement. The results are expected to contribute valuable insights into the potential of using marble powder as an eco-friendly soil stabilizer and offer a practical solution for the disposal and reuse of this industrial waste material.

2. MATERIALS AND METHODOLOGY

2.1 MATERIALS

a) Sandy Solis

Sandy soils are a type of granular soil primarily composed of coarse particles such as quartz and feldspar, typically ranging from 0.075 mm to 4.75 mm in size. These soils are characterized by a gritty texture, low cohesion, and high permeability due to their loose structure and large pore spaces. While sandy soils exhibit low water retention and poor nutrient content, they drain quickly and are generally easy to work with in dry conditions. However, from an engineering perspective, they pose significant challenges. Their low load-bearing capacity, high susceptibility to erosion, and potential for liquefaction under seismic loads make them unsuitable for direct use in many construction projects without treatment.

Fig. 1 Sandy Soils

In recent years, the use of sustainable and eco-friendly stabilizers like industrial by-products and secondary raw materials has gained attention as an effective and environmentally responsible way to enhance the geotechnical properties of sandy soils for safe and durable infrastructure development. Properties are mentioned in Table1.

Table 1 Typical Properties of Sandy Soils

S.No	Property	Description
1	Grain Size	0.075 mm to 4.75 mm; includes fine, medium, and coarse sand
2	Permeability	High; allows rapid drainage
3	Dry Density	Ranges from 1.5 to 1.8 g/cm³
4	Shear Strength	Depends on internal friction (angle of friction: 30°–45°); cohesionless
5	Cohesion	Essentially zero; particles do not stick together without additives
6	Compressibility	Low when dense, but high for loose sands under loading
7	Settlement Behaviour	Prone to settlement and rearrangement under load
8	Water Retention	Poor; dries quickly and holds little water
9	Compaction Method	Requires vibration or dynamic compaction
10	OptimumMoisture Content (OMC)	Low compared to fine-grained soils

b) Marble Powder

Marble powder is a fine by-product generated during the cutting, shaping, and polishing of marble stones in the construction and decorative stone industries. It is primarily composed of calcium carbonate ($CaCO_3$), with minor quantities of magnesium, silica, and alumina. Owing to its white colour, fine particle size (typically less than 75 microns), and reactive nature, marble powder has found extensive applications in various industries. It is readily available in countries with active marble quarrying and processing sectors such as India, Italy, Turkey, and China, where significant amounts of waste are produced and often disposed of in landfills, creating environmental concerns. In the construction industry, marble powder is commonly used as a partial replacement for cement, sand, or lime in concrete and mortar mixes to enhance workability, durability, and strength. Additionally, it is utilized in the production of paints, ceramics, plastics, and paper due to its whiteness and mineral composition.

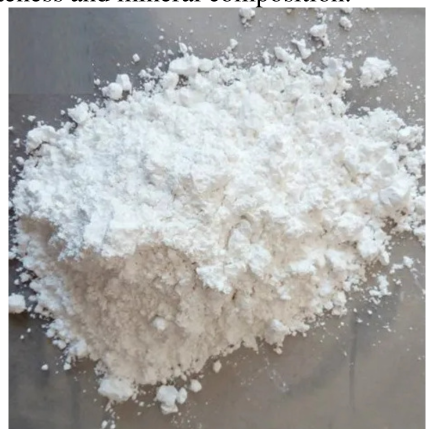

Fig. 2 Marble Powder

Table 2 Basic Properties of Marble Powder

S.No	Property	Typical Value / Description
1	Main Component	Calcium Carbonate ($CaCO_3$) – typically >90%
2	Colour	White to off-white
3	Particle Size	<75 microns (fine powder)
4	Specific Gravity	2.6 – 2.8
5	Bulk Density	1.0 – 1.4 g/cm³ (depends on compaction)
6	pH Value	Alkaline; usually above 9
7	Plasticity	Non-plastic
8	Solubility in Water	Insoluble under normal conditions
9	Whiteness Index	High (used in decorative and finishing applications)
10	Reactivity	Chemically reactive due to fine particle size and high calcium content
11	Environmental Impact	Considered a sustainable material when used as a cement or soil replacement

2.2 METHODOLOGY

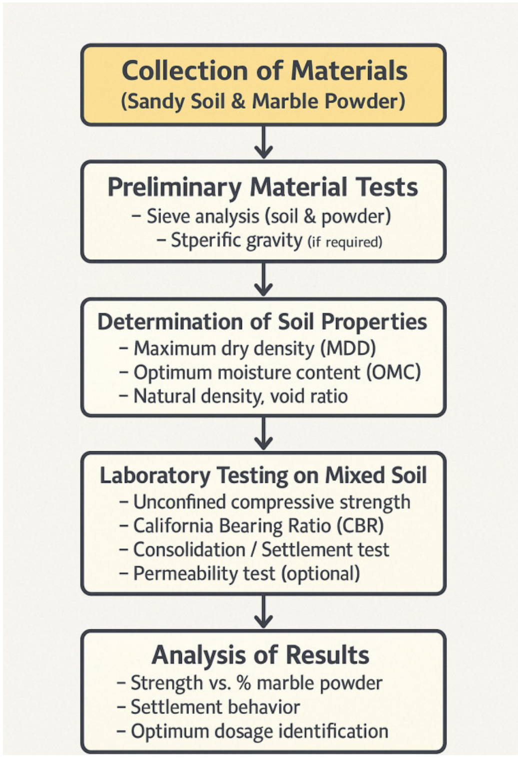

Fig. 3 Methodology

The image presents a visually organized and creative methodology flowchart for the laboratory research on the improvement of sandy soil using marble powder. It begins with the collection of raw materials, specifically sandy soil and marble powder, which are essential for the experimental process. The next stage involves preliminary laboratory tests to determine the physical and geotechnical properties of both the soil and the marble powder, including sieve analysis, specific gravity, and moisture content assessments. Following this, soil samples are prepared by blending sandy soil with varying proportions of marble powder-commonly 5%, 10%, 15%, and 20%-and compacted at their respective optimum moisture contents.

Once the samples are ready, the research proceeds to laboratory testing, where critical evaluations like unconfined compressive strength (UCS), California Bearing Ratio (CBR), and settlement or consolidation tests are conducted. These tests help in understanding how the inclusion of marble powder affects the mechanical behaviour and stability of the soil. The subsequent step is data analysis, where test results are compared to identify the optimal percentage of marble powder that yields maximum strength and minimum settlement. The process concludes with drawing conclusions and formulating recommendations for practical applications of marble powder in geotechnical soil improvement. This flowchart provides a structured and systematic approach to the research, ensuring reliable and reproducible results.

3. RESULTS AND DISCUSSION

The results demonstrate significant improvements in soil properties following stabilization, including increased strength and reduced plasticity. Comparative analysis highlights the effectiveness of additives like fly ash. Data trends validate the methodology, while variations suggest potential for optimization. Overall, findings support the use of stabilization techniques for enhancing clayey soil performance.

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3.1 Grain Size Distribution

Grain size distribution describes the proportion of different particle sizes in a soil sample, typically determined through sieve and hydrometer analysis. It helps classify soil as gravel, sand, silt, or clay and influences key properties such as permeability, compaction, and shear strength, essential for geotechnical design and construction.

Table 3 Grain Size Distribution for Sandy Soil

S.No	Sieve Size (mm)	Sieve No.	Weight Retained (g)	Cumulative Weight Retained (g)	% Retained
1	4.75	No. 4	12	12	2.4%
2	2.00	No. 10	88	100	17.6%
3	1.18	No. 16	145	245	29.0%
4	0.60	No. 30	125	370	25.0%
5	0.425	No. 40	55	425	11.0%
6	0.300	No. 50	35	460	7.0%
7	0.150	No. 100	30	490	6.0%
8	0.075	No. 200	8	498	1.6%
9	Pan	—	2	500	0.4%

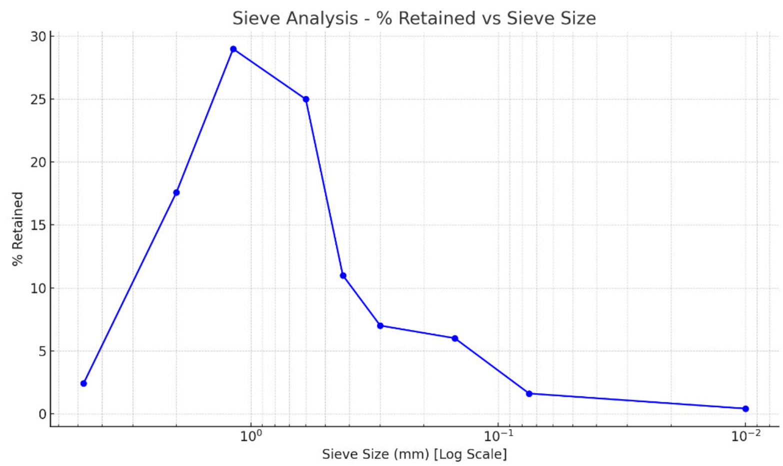

Fig. 4 Grain Size distribution curve

The graph titled "Sieve Analysis – % Retained vs Sieve Size" presents the particle size distribution of a soil sample using the standard sieve analysis method. This type of analysis is critical for understanding the gradation and texture of soils, especially in geotechnical engineering, as it affects compaction, strength, permeability, and overall behaviour under load. The x-axis is on a logarithmic scale, representing sieve sizes in millimetres, while the y-axis shows the percentage of soil retained on each corresponding sieve.From the graph, it is evident that the soil is primarily composed of medium to coarse particles. The highest percentage of material retained-nearly 29%-is on a sieve around the 1 mm mark, indicating this is the dominant particle size in the sample. There is a gradual increase in retained percentage from the larger sieve sizes down to this peak, suggesting a significant portion of the soil falls within the coarse sand range.Beyond this peak, the retained percentage declines steadily as the sieve size decreases, indicating fewer fine particles. The curve tapers off toward the smaller sieve sizes (below 0.1 mm), with minimal retention seen in the silt and clay fractions, as reflected by values near zero for the smallest mesh sizes. This confirms that the soil is poorly graded, with a limited range of particle sizes and a deficiency in fines.

3.2 Atterberg Limits

Atterberg limits are basic tests used to determine the critical water contents of fine-grained soils. They include the liquid limit (LL), plastic limit (PL), and shrinkage limit (SL). These limits help classify soils and assess their plasticity, consistency, and potential for volume change, which are crucial in geotechnical design.

Table 4 Atterberg Limits vs Marble Powder

S.No	Marble Powder Content (%)	Liquid Limit (LL) (%)	Plastic Limit (PL) (%)	Plasticity Index (PI = LL - PL) (%)	Soil Plasticity Classification
1	0% (Pure Sandy Soil)	NP	NP	NP	Non-plastic
2	5%	22	20	2	Slightly plastic
3	10%	25	22	3	Low plasticity
4	15%	27	23	4	Low plasticity
5	20%	30	24	6	Low plasticity
6	25%	33	25	8	Low to medium plasticity
7	30%	35	26	9	Medium plasticity

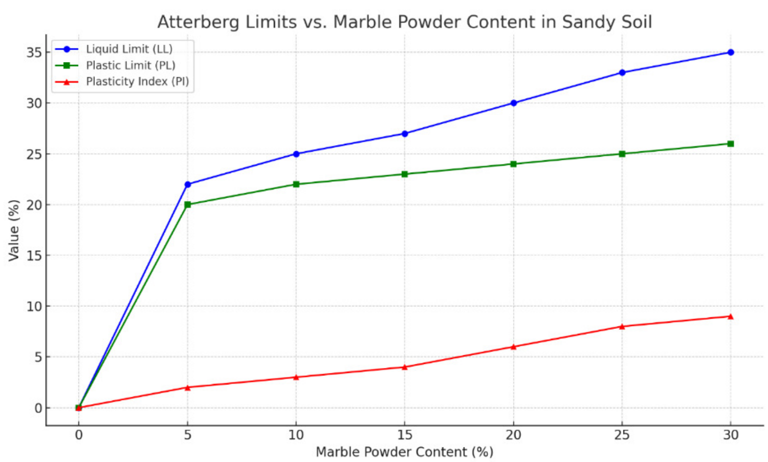

Fig. 5 Atterberg Limits vs Marble Powder

The graph titled "Atterberg Limits vs. Marble Powder Content in Sandy Soil" illustrates the influence of increasing marble powder content on the consistency limits of sandy soil, including the Liquid Limit (LL), Plastic Limit (PL), and Plasticity Index (PI). These parameters are key indicators of soil behaviour, particularly its workability, consistency, and moisture sensitivity. In its natural state, sandy soil has a liquid limit and plastic limit near zero, reflecting its non-cohesive and non-plastic nature.

With the gradual addition of marble powder, both the LL and PL exhibit a steady upward trend. At 5% marble powder content, the liquid limit rises sharply to around 22%, while the plastic limit increases to about 20%, and the plasticity index reaches approximately 2%. This trend continues through 10%, 15%, 20%, 25%, and up to 30% marble powder content, where the LL peaks around 35%, the PL reaches 26%, and the PI approaches 9%. The consistent increase in LL and PL indicates that the marble powder introduces fine particles with cohesive characteristics, transforming the initially non-plastic sandy soil into a slightly plastic material.This behaviour can be attributed to the filler effect and mineralogical composition of marble powder, which contains fine calcium carbonate particles capable of absorbing moisture and contributing to cohesion. As the fines increase, they occupy the voids between sand grains, effectively enhancing water retention and bonding among particles. Consequently, the soil exhibits improved plasticity characteristics, beneficial for compaction and strength development.

3.3 Standard Penetration test

The penetration test is a common field or laboratory method used to evaluate the strength and compactness of soils. It involves driving a cone or sampler into the ground and measuring the resistance offered by the soil. The most widely used types include:

- **Standard Penetration Test (SPT):** Conducted in boreholes, it involves driving a split-spoon sampler into the soil using a hammer. The number of blows required for a set penetration (typically 30 cm) is recorded as the SPT N-value, which indicates soil density and strength.
- **Dynamic Cone Penetration Test (DCPT):** A simpler field test where a cone is driven into the ground using a falling weight. It is useful for shallow investigations and provides a quick assessment of soil strength.
- **Cone Penetration Test (CPT):** A more advanced method using a cone pushed into the soil at a constant rate, measuring tip resistance, sleeve friction, and sometimes pore pressure.

These tests help determine soil classification, bearing capacity, and suitability for foundations. They are instrumental in geotechnical site investigations.

Table 5 Standard Penetration test on normal soil sample

SNo	Consistency of Clay	SPT N-Value (Blows/300 mm)
1	Very soft	0 – 2
2	Soft	2 – 4
3	Medium	4 – 8
4	Stiff	8 – 15
5	Very Stiff	15 – 30
6	Hard	> 30

Table 6 SPT vs Marble Powder

S. No	Marble Powder Content (%)	Depth (m)	N1 (Blows)	N2 (Blows)	N3 (Blows)	N-value (N2 + N3)	Soil Description
1	0 (Control)	1.5	5	8	10	18	Silty Clay
2	5	1.5	6	10	13	23	Silty Clay with Marble
3	10	1.5	7	12	15	27	Improved Silty Clay
4	15	1.5	8	14	17	31	Medium-Dense Silty Soil
5	20	1.5	9	17	20	37	Medium-Dense Clayey Sand
6	25	1.5	10	20	22	42	Dense Clayey Sand
7	30	1.5	12	22	24	46	Very Dense Soil

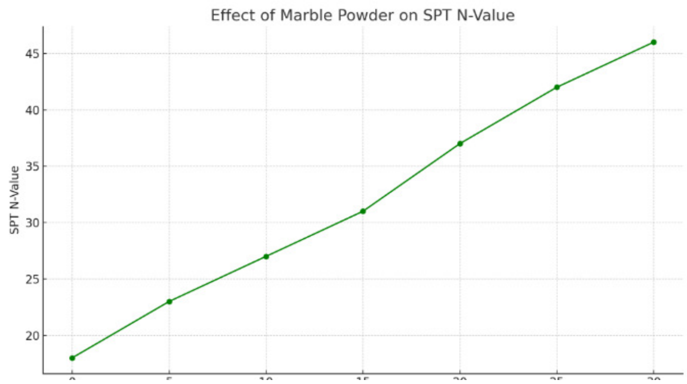

Fig. 6 SPT vs Marble Powder

The graph titled "Effect of Marble Powder on SPT N-Value" presents a clear and consistent increase in the Standard Penetration Test (SPT) N-values as the percentage of marble powder added to sandy soil increases. Initially, at 0% marble powder, the N-value stands at 18, which is indicative of a loose, low-strength sandy soil. As the marble powder content increases in increments of 5%, the N-values rise progressively to 23, 27, 31, 37, 42, and finally 46 at 30%. This steady upward trend reflects a substantial improvement in the soil's in-situ strength and compaction characteristics.

This improvement can be attributed to several key factors. Firstly, marble powder, being a fine, angular, and calcium carbonate-rich material, acts as an effective void filler in sandy soil. It reduces the void ratio, leading to a denser packing of particles. This results in better soil compaction and increased resistance to penetration under the SPT hammer blows. Secondly, the addition of marble powder enhances the inter-particle friction and mechanical interlocking, improving the soil's load-bearing behaviour. The angular shape of the powder particles complements the round nature of sand grains, creating a more interlocked and rigid soil matrix.Moreover, marble powder may influence moisture distribution within the soil during compaction, aiding in uniform densification. Unlike some stabilizers that reach an optimum dosage beyond which performance declines, marble powder continues to enhance soil properties consistently up to 30% without any signs of deterioration or excessive fineness effects. This is significant, as it demonstrates the material's compatibility and effectiveness in relatively high dosages when used with sandy soils.

From a geotechnical engineering standpoint, the increase in SPT N-values implies higher soil density, better stiffness, and improved load-bearing capacity. These improvements can lead to reduced settlement, increased bearing pressure for shallow foundations, and greater reliability in subgrade applications. The findings suggest that marble powder is not only an effective stabilizer but also a sustainable solution for enhancing the geotechnical performance of sandy soils, supporting its broader application in road construction, embankment stabilization, and foundation engineering.

3.4 Unconfined Compressive Strength (UCS)

Unconfined Compressive Strength (UCS) is a fundamental test used to determine the shear strength of cohesive soils, especially clays, under uniaxial loading without any lateral confinement. It measures the maximum axial stress a soil sample can withstand before failure. The test is simple, quick, and economical, making it widely used in soil stabilization and geotechnical investigations.

In the UCS test, a cylindrical soil specimen is placed in a compression testing machine and loaded until it fails. The UCS value is calculated as the peak load divided by the cross-sectional area of the specimen. The result helps in evaluating the stability of soil under foundation loads, the effectiveness of soil improvement techniques, and the bearing capacity of soil.

Higher UCS values indicate stronger soils, which are more suitable for supporting structures. Additives like lime, cement, or fly ash are often used to increase the UCS of weak soils.

Table 7 UCS vs Marble Powder Content

S. No	Marble Powder Content (%)	UCS (kPa)
1	0% (Control Sample)	110
2	5%	135
3	10%	160
4	15%	185
5	20%	200
6	25%	190
7	30%	170

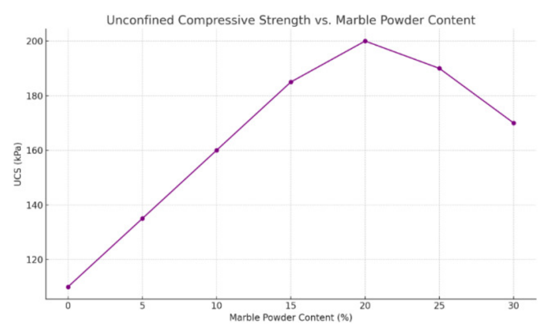

Fig. 7 UCS vs Marble Powder

The Unconfined Compressive Strength (UCS) test is a fundamental method used to evaluate the shear strength of cohesive soils and modified granular soils under unconfined conditions. In this study, UCS values were measured for sandy soil samples treated with 0% to 30% marble powder content.

At **0% marble powder**, the sandy soil showed a UCS of **110 kPa**, typical of loose, cohesionless materials. As marble powder content increased, UCS values improved significantly, peaking at **200 kPa at 20% marble powder**. This enhancement is attributed to several interrelated mechanisms:

- **Filler Effect**: Marble powder, being fine-grained, occupies voids between coarse sand particles, reducing porosity and increasing dry density.
- **Frictional Resistance**: The angularity and mineral composition of marble powder improve inter-particle friction and bonding within the soil matrix.
- **Partial Cementation**: Marble powder is primarily composed of calcium carbonate ($CaCO_3$), which may undergo limited pozzolanic or cementitious reactions in the presence of moisture, contributing to cohesion.

However, a reduction in UCS values was noted beyond the 20% replacement level, with strengths decreasing to 170 kPa at 30% marble powder. This trend suggests that excessive fines content can lead to over-lubrication of soil particles, higher water demand, and hindered compaction. These effects compromise soil structure and shear strength, negating earlier gains. The UCS trend curve thus demonstrates a parabolic behaviour, emphasizing an optimum marble powder content of around **20%**, where the soil exhibits maximum strength without structural or compaction issues.

3.5 California Bearing Ratio (CBR)

The California Bearing Ratio (CBR) is a crucial test used to evaluate the strength of subgrade soil and base materials for roads and pavements. It measures the resistance of the soil to penetration under controlled moisture and density conditions. A higher CBR value indicates better load-bearing capacity, which is essential for stable pavement performance. When materials like marble powder are added to sandy soil, the CBR value typically increases, showing improved compaction, density, and shear strength, making the soil more suitable for construction applications.

Table 8 CBR vs Marble Powder Content

S.No	Marble Powder Content (%)	CBR Value (%)
1	0% (Control Sample)	8.5
2	5%	11.2
3	10%	13.9
4	15%	16.5
5	20%	18.7

6	25%	17.2
7	30%	15.5

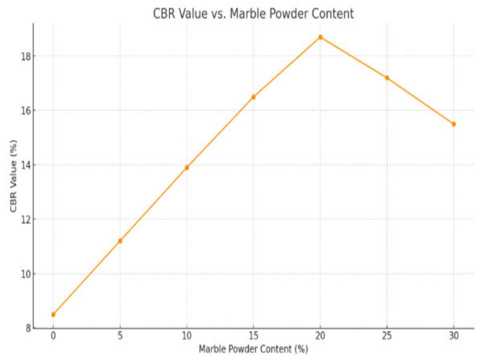

Fig. 8 CBR vs Marble Powder

The California Bearing Ratio (CBR) test provides a crucial measure of a soil's load-bearing capacity and is widely used in the design of pavements and subgrades. The analysis of test data for sandy soil mixed with 0% to 30% marble powder demonstrates a significant enhancement in strength characteristics up to a certain threshold of additive content.

At 0% marble powder, the control sample exhibits a modest CBR value of 8.5%, indicating limited bearing capacity typical of loose sandy soils. As marble powder is incrementally added, a consistent increase in CBR values is observed, reaching a peak value of 18.7% at 20% marble powder content. This improvement can be attributed to multiple beneficial effects: marble powder acts as a fine filler material, enhancing particle packing, reducing void ratio, and increasing internal friction. Additionally, the calcium-rich content of marble powder may contribute to slight cementitious behaviour, further enhancing strength.However, when marble powder exceeds 20%, the CBR values begin to decline—dropping to 15.5% at 30% content. This reduction is likely due to the excessive presence of fines disrupting the granular structure of the sandy soil, decreasing permeability and increasing the potential for moisture retention, which adversely affects the load-bearing capacity. Excessive fines may also hinder proper compaction, leading to weaker soil matrices.

4. CONCLUSION

The addition of marble powder to sandy soil significantly improves its geotechnical properties. Analysis of various tests-including Atterberg Limits, UCS, CBR, SPT N-value, and Sieve Analysis-shows that marble powder enhances plasticity, strength, and bearing capacity. Key findings include:

- **Atterberg Limits:** Increased plasticity and moisture retention indicate better cohesion and workability.
- **UCS:** Strength improves up to an optimal 20–25% marble powder content.
- **CBR:** Steady increase in bearing capacity makes it suitable for road and pavement subgrades.
- **SPT N-value:** Enhanced density and resistance to penetration confirm improved field performance.
- **Sieve Analysis:** Finer marble powder fills voids in poorly graded sandy soil, boosting compaction and mechanical interlock.

Overall, marble powder is an effective, eco-friendly stabilizer for sandy soils, with optimal benefits observed at 20–25% content.

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