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Soil Improvement Using Waste Marble Dust for Sustainable Development

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Abstract

The soils which show very high shear strength in a dry state but rapidly lose their strength on wetting are known as collapsible soils. Such rapid and massive loss of strength produces severe distress leading to extensive cracking and differential settlements, instability of building foundations, and even collapse of structures built on these soils. Waste marble dust is an industrial byproduct and is being produced in large quantities globally poses an environmental hazard. Therefore, it is of the utmost need to look for some sustainable solution for its disposal. The present study focused on the mitigation of the collapse potential of CL-ML soil through a physio-chemical process. The soil is sensitive to wetting, warranting its stabilization. Waste marble dust (WMD) in varying percentages was used as an admixture. The study's optimization process showed that geotechnical parameters of collapsible soil improved substantially by adding waste marble dust. Plasticity was reduced while Unconfined Compressive Strength (UCS) significantly increased while swelling was reduced to an acceptable limit. The California Bearing Ratio (CBR) also exhibits considerable improvement. This study appraises the safe disposal of hazardous waste safely and turns these into suitable material for engineering purposes.

Keywords: Soil Stabilization; Waste Marble Dust; Collapse Potential; Waste Utilization; Collapsible Soils.

1. Introduction

Collapsible soils are moisture sensitive soils that show a huge decrease in volume after wetting. These soils normally consist of silts and fine sands. These soils are traceable throughout the world but are mainly found in dry to semi-dry regions [1]. Saturation in the Collapsible soils causes a rapid decrease in the volume, especially under an additional load. Such situations cause excessive deformation in the soil, destructive for the structures [2].

Structures built on collapsible or expansive soils are vulnerable to destruction and failure. The collapsible soil includes; Loess deposits, Aeolian deposits, Alluvial deposits, Colluvium deposits, Volcanic tuff, and Residual soils [3]. The structures built on such soils have been severely damaged in the past. Fifteen hundred and five (1505) buildings and 80 km long underground pipeline were severely damaged in China due to these collapse incidents during 1974-75 [4].

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Such collapsible soil should be stabilized to reduce the hazards of sudden collapse, rocking, settlements, and associated damages [5, 6]. The soil stabilization process involves the improvement of soil properties in terms of strength and durability. For this purpose, various densification methods are employed at rural areas or those sites that can potentially develop collapsible conditions. Methods used for this purpose include cement, bitumen, or special additives to bind the soil particles [7].

To attain the Sustainable Development Goals (SDGs), conservation of energy & resources and efficiently recycling solid waste products has become a global concern that requires extensive research to explore novel applications of waste materials [8]. Keeping in view the protection of the environment from the waste product's deposition; industrial byproducts can be used solely or as an additive to utilize natural resources effectively [9].

The marble industry in Khyber Pakhtun Khaw (KPK), a Northern Province of Pakistan, is growing rapidly. Marble reserves of this region contribute 97% of Pakistan's total marble deposits [10]. More than 1500 marble processing units (MPUs) are working in the province, generating a large amount of waste products in the form of marble slurry and irregular pieces. Forty to seventy (40-70%) percent of this material is wasted during quarrying, processing, polishing operations, and deteriorating surface water [11]. The marble processing plants dump the waste marble in nearby pits or vacant lands. It leads to serious environmental hazards and dust pollution along with the occupation of vast land areas.

Waste Marble Dust (WMD) is used for different purposes as a reinforcement or raw material. The most common areas and applications are Brick [12], building material [13, 14], ceramic [15], infiltration processes [16].WMD is also useful in white cement, mosaic, mortar, and tiles [17] and is used to produce clay-based materials and polymer-modified mortars [18]. Coarse waste marble is used as a filler [9], and it can replace aggregate in asphalt pavement applications [19]. WMD can also be used in clinker production [20]. El-Sayed et al. (2018) reported that marble dust can be safely added up to 5% by weight in the cement as a replacement of gypsum, proving to be an energy and financial saving concept [21].

In developing countries, storage and mishandling of waste material have resulted in accumulative environmental pollution. The utilization of WMD appears to be a solution to the environmental problems and will decrease construction costs and storage, handling problems associated with waste material [22]. Deboucha et al. (2020) investigated the effect of marble dust and ceramic waste on the performance of road sub-base layer in terms of CBR, MR, and MDD. The study concluded that MD and CW combined with a small amount of OPC could be an effective alternative for soil stabilization for use in the sub-base layer of roads [23]. Moghadam and Hadiani (2018) stabilized the excavated material containing demolished building materials using cement and lime with 1.5 to 3.5% replacement. Desired CBR values were attainted for in-situ soil stabilized with the addition of higher percentages of cement and lime [24].

Sabat et al. (2011) reported that the mixing of marble dust and rice husk with soil acts as a catalyst in its stabilization. With the addition of WMD, the strength increases while the potential swelling decreases, and WMD made the soil and rice husk ash mixture durable [25]. Ismaiel and Hussin (2006) used bagasse ash and WMD for the improvement of expansive soils. It was concluded that WMD has a significant impact on the characteristics of expansive soils [26]. Agrawal and Gupta (2011) added marble dust as a soil stabilizer and reported that marble dust decreases liquid limit, plasticity index, shrinkage index, and increases plastic limit and shrinkage limit [27].

Bhavsar and Patel (2014) examined collapsible and expansive soils' swelling characteristics by mixing WMD in different percentages (from 30 to 50%) and reported Its effectiveness for reducing the swelling potential and contraction properties of black cotton soil [28]. The effect of WMD dosage (0 to 40%) on dark cotton soil was recorded by Mudgal (2014) [29]. The decrease in the liquid limit from 57.67 to 33.9% was recorded. With the increasing WMD dosage, the plasticity index reduced from 28.35 to 16.67%, and the shrinkage limit increased from 8.06 to 18.39%. Additionally, the swell potential was reduced from 66.6 to 20.0%.

Abdulla et al. (2014) investigated the soils (CL and CH) of Erbil and Bastora airport. Various percentages of WMD were added by weight to the soil. The outcome exhibit that increasing the WMD percentage decreases the liquid limit, plastic limit, plasticity index, and swelling potential [30]. Abdulla and Majeed (2021) evaluated the mechanical stabilization of expansive soil by adding 10, 20, and 30% WMD obtained from three different resources. It was concluded that an increase in the percentage of marble dust decreases the swelling potential of expansive soils [31].

Gupta and Sharma (2014) used WMD and fly ash to evaluate their effect on the subgrade characteristics of dark cotton soil. CBR strength was improved up to 200% with the addition of 15% addition of WMD [32]. Saygili (2015) investigated the impact of WMD on clayey soils by adding WMD varying from 0-30% of the soil's weight [22]. The results demonstrated that with the addition of WMD to the soil, the shear strength was improved, whereas the swell potential was greatly reduced. Bansal and Sidhu (2016) studied the effect of WMD on the soil by varying its content from 0 to 30% [33]. The Liquid limit showed a reduction from 31.70 to 25%, while the plastic limit increased from 17.69 to 19.26%. It was further noted that the soil's optimum moisture content decreased from 18 to 14.10%, and the maximum dry density showed an increase from 1.738 to 1.884 gm/cc. Furthermore, CBR Value increased from 2.46 to 6.07%.

Jain et al. (2020) determined the potential utilization of waste marble dust as a geo-material for improving geotechnical properties of expansive soil and particles interactive mechanism. The results revealed that marble dust could effectively control swelling and improve the plasticity of the soil. The factors responsible for controlling the interactive behavior of marble added soils were the mineralogical, chemical, and elemental composition of marble dust and soil type [34].

Kumar and Tamilarasan (2015) noticed that the Optimum Moisture Content (OMC) of clay showed an increase from 18 to 24%, and the maximum dry density (MDD) increases up to 10% with the addition of WMD and then reduces with further addition of WMD to the soil. WMD was added in different percentages of 5 to 25% with an increment of 5%. The liquid limit value decreased from 70 to 55% constantly by adding WMD. The plastic limit value showed a 25 % increase approximately [35]. Mishra et al. (2015) utilized quarry dust mixed with lime. The increase in OMC from 23 to 25.1% was observed while increasing quarry dust; MDD reduced from 1.83 to 1.71gm/cc. UCS increases up to a required 30% with an optimum strength value of 19.60 kg/m^2. The swell potential of the soil was decreased from 85 to 45% [36].

Sivrikaya et al. (2020) studied geotechnical properties of two fine grained soil with different plasticity by adding calcitic marble powder (CMD) and dolomitic marble powder (MDP) in 5, 10, 20, 30, 50%. A significant decrease in the index properties, expansion index, and Cc & Cs of both soils was observed with CMD and MDP [37]. Gupta and Sharma (2014) carried out soil stabilization with sand and fly ash by replacing soil with WMD from 0 to 20%. Results showed that a 15% addition of WMD to soil gives the optimum results. The optimum ratio of Marble dust: Fly ash (Sand): Soil; was found out to be 13.20: 22.44: 52.36%. An increase of 200% was observed in soaked CBR values [32].

The study's objective is to evaluate the effectiveness of locally available WMD for controlling swell resistance of collapsible soils and CBR improvement to make it useable in geotechnical applications. The evaluation involves determining the swelling potential of collapsible soil in its natural state and mixed with a varying proportion of marble dust.

2. Materials and Methods

The study entailed potentially collapsible soil and WMD characterization, soil modification with WMD, and evaluation/quantification of resulting improvement. Characterization of soil was typically done by evaluating its consistency limits and gradation. Mainly, the effect of moisture on the subgrade/ foundation soil has been studied by comparing the swelling potential, California bearing ratio (CBR), and unconfined compressive strength (UCS) values of treated and untreated soil.

Table 1. Geotechnical Properties of Untreated Soil

Geotechnical Property	Standard Method	Value
Liquid limit	ASTM D 4318	27%
Plastic Limit	ASTM D 4318	22.06%
Plasticity index	ASTM D 4318	4.9%
Specific gravity	ASTM D 854	2.67
Maximum dry density	ASTM D 689	18.34 KN/m^3
OMC	ASTM D 689	15.7%
CBR value	AASHTO T 193	4.50%
UCS value	ASTM D 2166	101.08 KN/m^2
Soil classification	ASTM D 2487	CL-ML
Grain size distribution	ASTM D 6913	Sand (37.8%), Silt and Clay (62.2%)

2.1. Materials

Soil

The collapsible soil was collected from a semiarid region in northern Pakistan, as shown in Figure 1. The collected soil was classified according to the unified soil classification system [39] and was found to be CL-ML. The summary of test results performed to determine the basic geotechnical properties of the selected soil is presented in Table1. Table 1; shows that the soil was clayey silt with a Plasticity Index (PI) of about 4.9%. CBR and UCS values are low due to lesser clay contents; exhibited by its PI. The soil structure would collapse upon wetting; clay coating over silt and sand particles would get washed. Test results suggested that the soil required modification to control its collapse potential and CBR value.

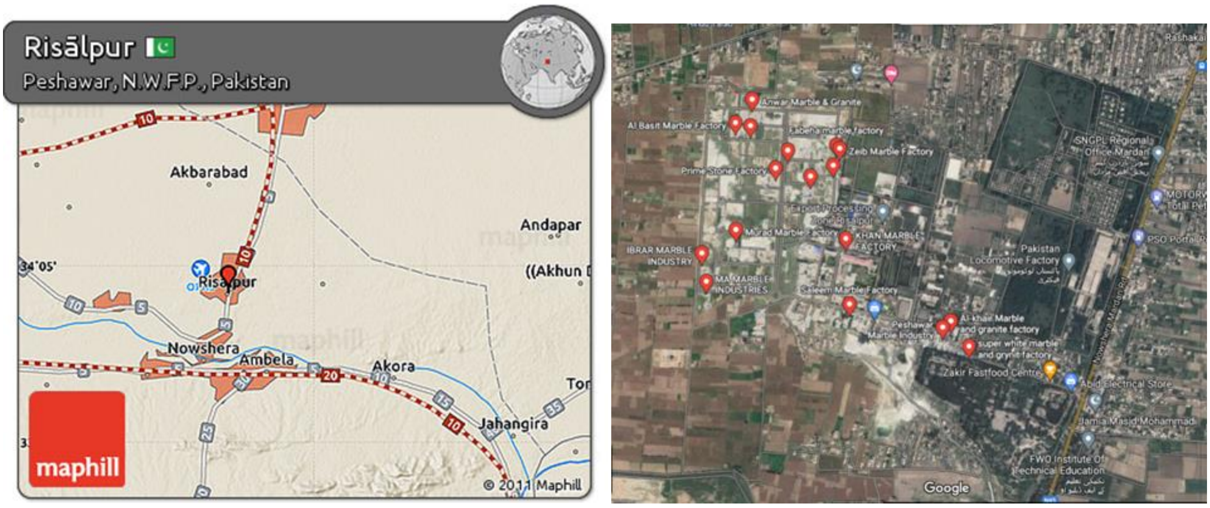

Figure 1. Study area locator map and sample collection points

Waste Marble Dust

Waste marble dust (WMD) was obtained from the sludge drain of the marble factory. Marble sludge, a waste material/constituent formed as a by-product of water jet cutting of marble blocks in the marble industry, was taken from native marble cutting plants. WMD is mainly composed of calcium, silica, alumina, which significantly help stabilize the soil. The test results of WMD are given in Table 2. As shown in Table 2, WMD has PI = 3.4, which showed almost non-plastic material.

Table 2. Marble Dust index Properties

Serial No	Property	Value
1.	Fineness Modulus	0.46
2.	Liquid limit	22.20%
3.	Plastic Limit	18.79%
4.	Plasticity index	3.4%

3. Test Methods

The tests were performed according to relevant ASTM and AASHTO Standards; the standard designations are referred to, where applicable. Figure 2 illustrates the research methodology.

3.1. Optimization Process

The bulk soil sample and WMD were air-dried, lumps broken, pulverized, and passed through #10 sieves. The WMD in the proportion/percent by mass of dry soil was mixed manually. Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) for each combination of WMD were computed as per ASTM D-698 [40].

3.2. Unconfined Compressive Strength Test (UCS)

Testing aims to investigate the effect of mixing WMD on the strength of the soil. The unconfined compressive strength of collapsible soil was determined by loading a cylindrical specimen axially on the sample in unsoaked condition. Tests were performed according to ASTM D 2166 [41]. Each sample was prepared with the compaction energy corresponding to the standard proctor compaction energy. Prepared samples had a diameter of 50 mm and a height of 100 mm. Three samples were prepared and tested against each dosage of WMD. A newly calibrated, electrically operated UCS machine was used with a ring constant of 0.28 kg/division. The least count of deformation gauge of 0.01 mm. Figure 3 shows a UCS testing machine with a tested soil sample.

3.3. California Bearing Ratio Test (CBR)

CBR test is conducted to assess the potential quality of subgrade, subbase, and base course material, including reusable materials for its use in road pavements and landing strips [42]. Waste marble dust was added to soil in percentages of (5, 10, 15%) respectively. A total of 48 moulds were prepared for soaked and unsoaked CBR. For each specimen, three moulds were prepared with 10, 30, and 65 blows, and CBR values were calculated against 95% MDD. CBR tests were carried out in accordance with the standard method of AASHTO (T-193) [43]. A newly calibrated, electrically operated CBR machine was used with a ring constant of 10 lbs and plunger diameter 3-inch square. The least count of deformation gauge of 0.01 mm with a lower strain rate of 1.27 mm/minute was used to ensure precision in data generation. Unsoaked samples were allowed to heal for 0, 3 and 7 days, and the CBR tests were conducted after the healing period. Figure 4 presents CBR test samples.

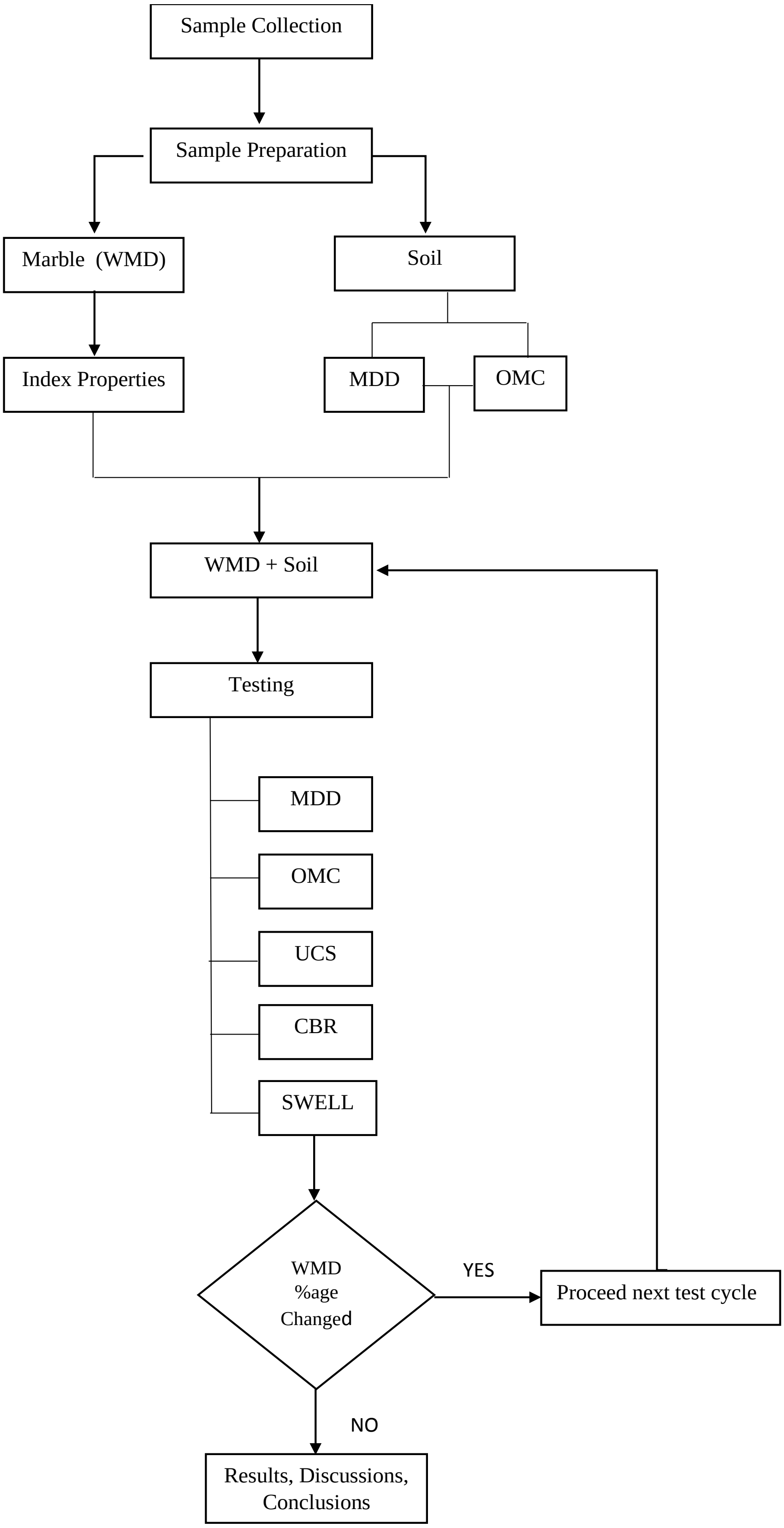

Figure 2. Flow chart illustrating the research methodology

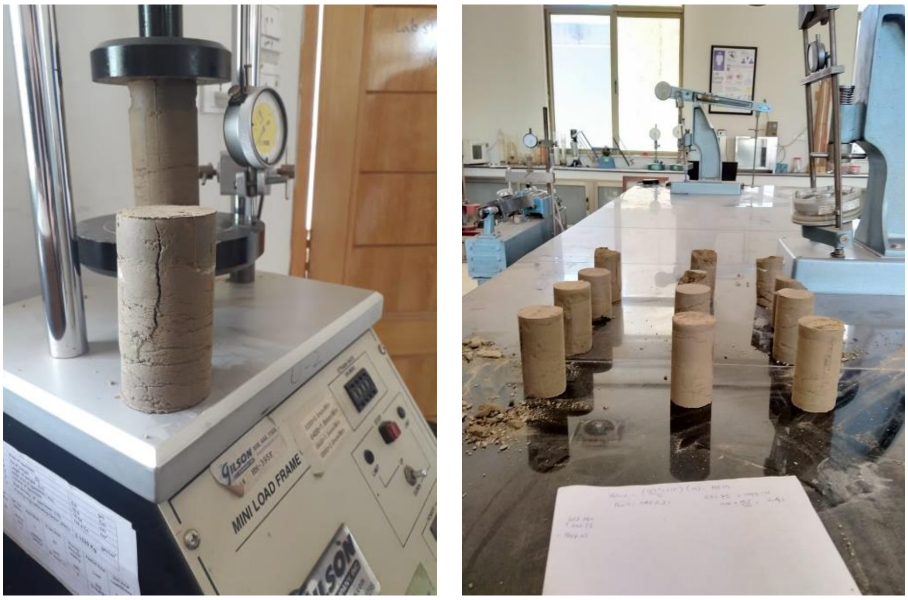

Figure 3. UCS machine and failed samples

Figure 4. CBR test and prepared samples

3.4. Swell Potential

The swelling potential of collapsible soil samples was determined after 96 hours of soaking of the moulds. Swell potential of 12 CBR samples prepared with 10, 30, and 65 blows respectively against 0, 5, 10, and 15% dosage of WMD were determined with the help of dial gauges. Three dial gauges of 0.01mm least count were installed on each sample, and the average value of three gauges was reported.

4. Results and Discussion

4.1. Effect of WMD on OMC and MDD

Average results for the OMC and MDD at different percentages of WMD are shown in Figure 5. The results depict that the Optimum Moisture Content (OMC) rose from 15.7% to 18.22%, showing a directly proportional relation with WMD dosage. Contrarily, Maximum Dry Density (MDD) decreased from 18.34 to 17.85 KN/m^3, decreasing with rising percentages of WMD addition. WMD is a non-plastic material, and the water-holding capacity of soil mix increases with the addition of WMD, confirming the findings of Zhang et al. (2009) [44], which results in increased OMC. A similar decrease in MDD was reported by Deboucha et al. (2020) [23] with a 5% addition of marble dust in fine grained soil. OMC increased from 10.78% to 12.96%. A decrease in MDD was observed with the addition of WMD, which is because of the flocculated and agglomerated clay particles (caused by the cation exchange reaction) which occupy large spaces and increase the volume of voids, consequently reducing the weight-volume ratio [45].

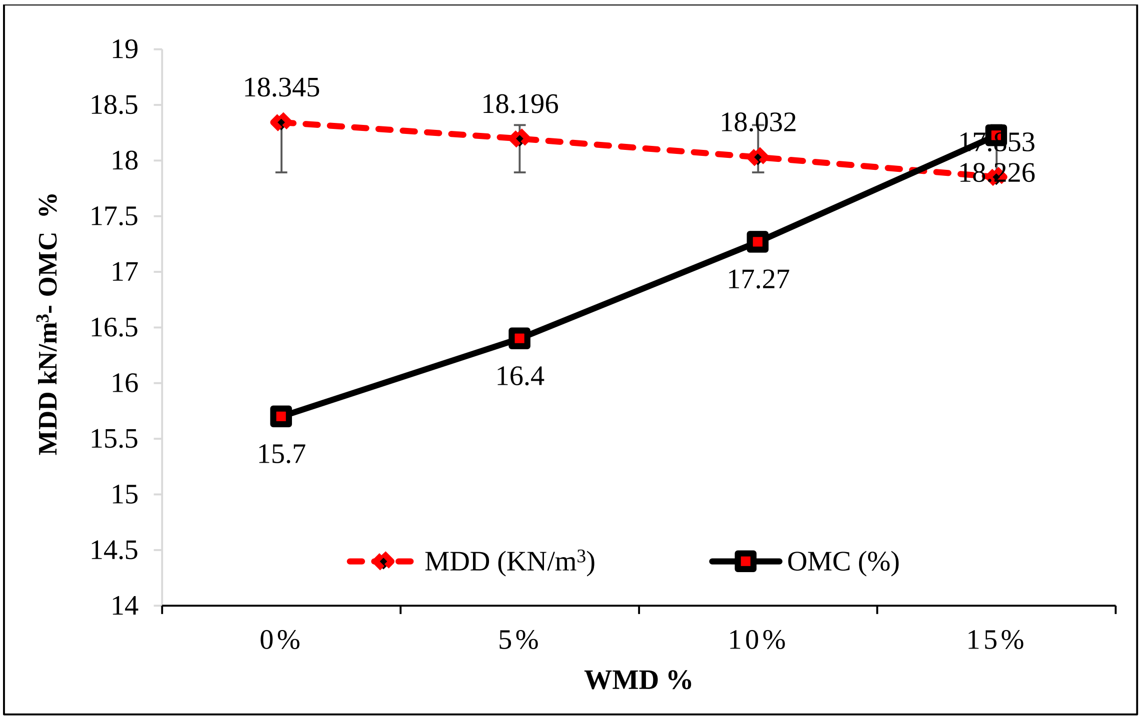

Figure 5. Effect of WMD on OMC and MDD

4.2. Effect of WMD on UCS

The results of UCS are shown in Figure 6. The graph depicts a strong correlation between UCS and WMD, as a prominent increase in the UCS value can be seen with increasing WMD up to 10%. The optimum value of UCS was acquired as 202.017 KN/m^2 at 10 % addition of Marble Dust. The increase in the UCS value is much higher from 0 to 10 % than from 10 to 15%, where the values start decreasing.

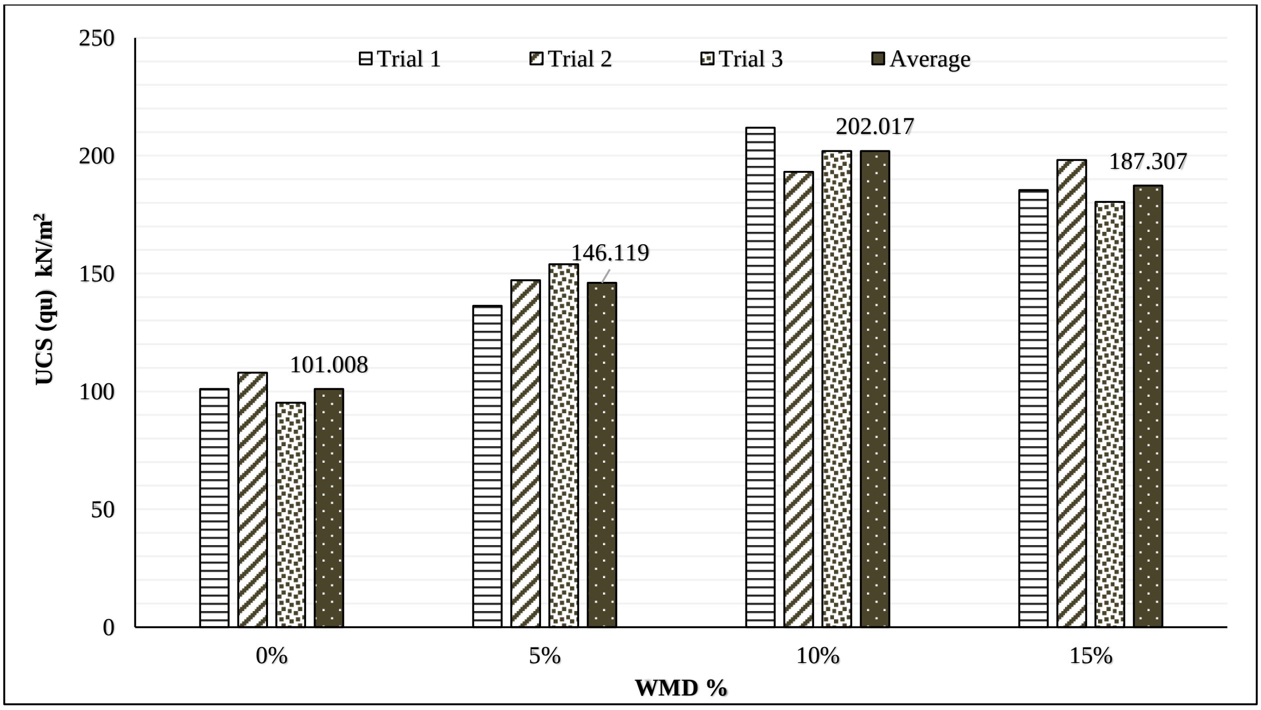

Figure 6. UCS values against WMD%

The mix's unconfined compressive strength increased up to 100% at 10% WMD content. The inclusion of marble dust decreases the clay content in mixed soil, and the proportion of the coarser particles increased. A mild pozzolanic reaction took place in the presence of water. This reaction produced stable calcium silicate hydrate, generated long term strength gain, and improved the UCS of the soil. The increase in the UCS may be attributed to calcium carbonate present in WMD.

A similar trend was observed by Sabat et al. (2015) [46], who found a threshold value at 9% content while adding limestone dust to the expansive soil. The maximum UCS value of the soil stabilized with marble dust by Saygili (2015) [22] and Sabat et al. (2011) [25] was obtained at 20% WMD, while at 20 to 25% WMD content, the value decreased. Pastor et al. (2019) obtained a 148% increase in the UCS of soil stabilized with limestone powder at 15% addition, above which the values of UCS dropped. The mixed soil stress-strain behavior moves as the quantity of limestone waste rises, away from the common soft soil behavior [47].

4.3. Effect on Swelling

The results of swelling with different WMD dosages after 96 hours of soaking are shown in Figure 7. The swell potential was evaluated for the samples compacted with 10, 30, and 65 blows [43]. The higher values of swell % of soil at its natural state show the soil's expansive nature. The WMD addition decreased the swell % to an acceptable limit of 0.3% [48]. The addition of marble dust in the soil changes the geotechnical properties of soil. The cohesive properties of treated clay particles decreased as it starts behaving as granular material after soaking. Reduction in the swell potential after the addition of WMD has also been reported by Okagbue and Onyeobi (1999) [45] and Cai et al. (2006) [49].

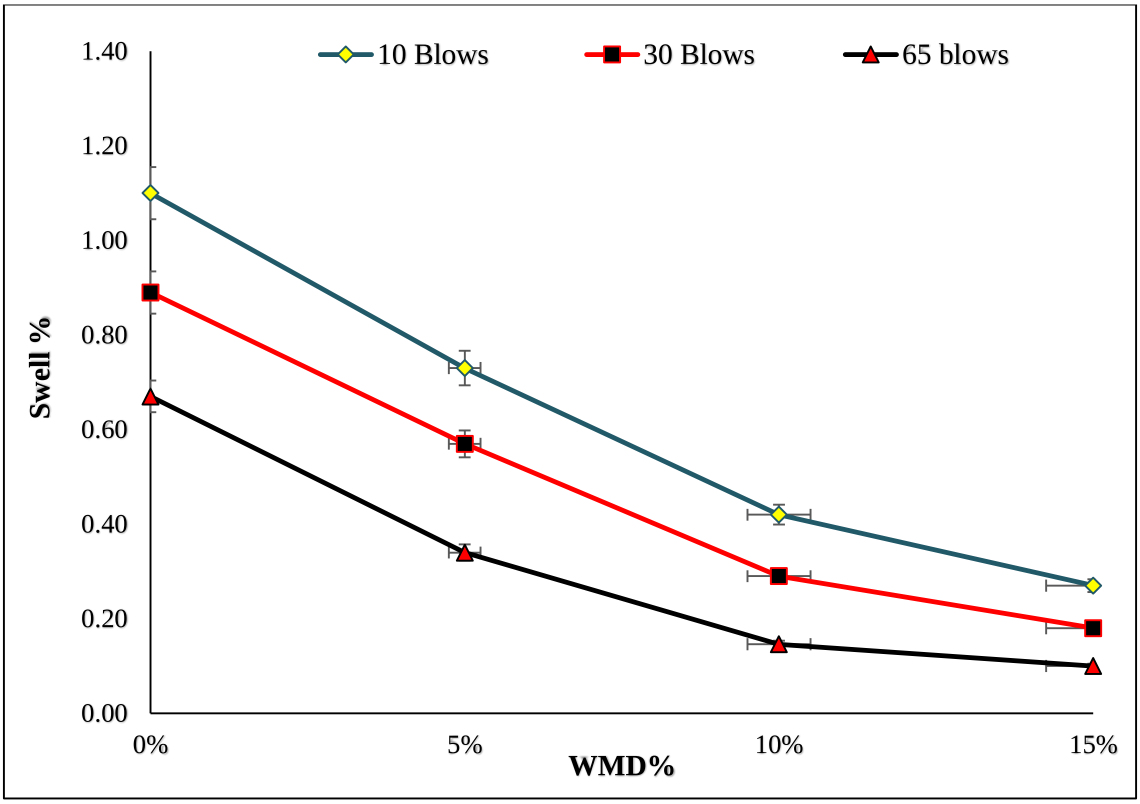

Figure 7. Swell percentage vs. WMD%

Aggregation of the soil particles by the WMD and soil reaction reduces the size of pores in the soil matrix and weakens the cohesive forces; as the soaking extends, it becomes difficult for the moisture to enter the clay matrix causing the soil to swell. The strengthening of the interparticle bond due to the cementitious effect of WMD plays an important role in reducing the swelling potential of soil.

4.4. Unsoaked CBR

Results of the CBR test conducted on unsoaked samples are given in Figure 6. Unsoaked samples were healed for 0, 3, and 7 days to observe the effect of healing and WMD on the CBR values. The CBR values were obtained at 95% of MDD. The addition of WMD increased the CBR value till 10%, after which the values dropped down. The healing period on CBR value is quite prominent; as the healing period of the soaked samples increased, the CBR values are also improved. The CBR value of samples with 7 Days of healing increased from 6.5 to 11.3 % at 10% WMD. Figure 8 presents the results of unsoaked tests.

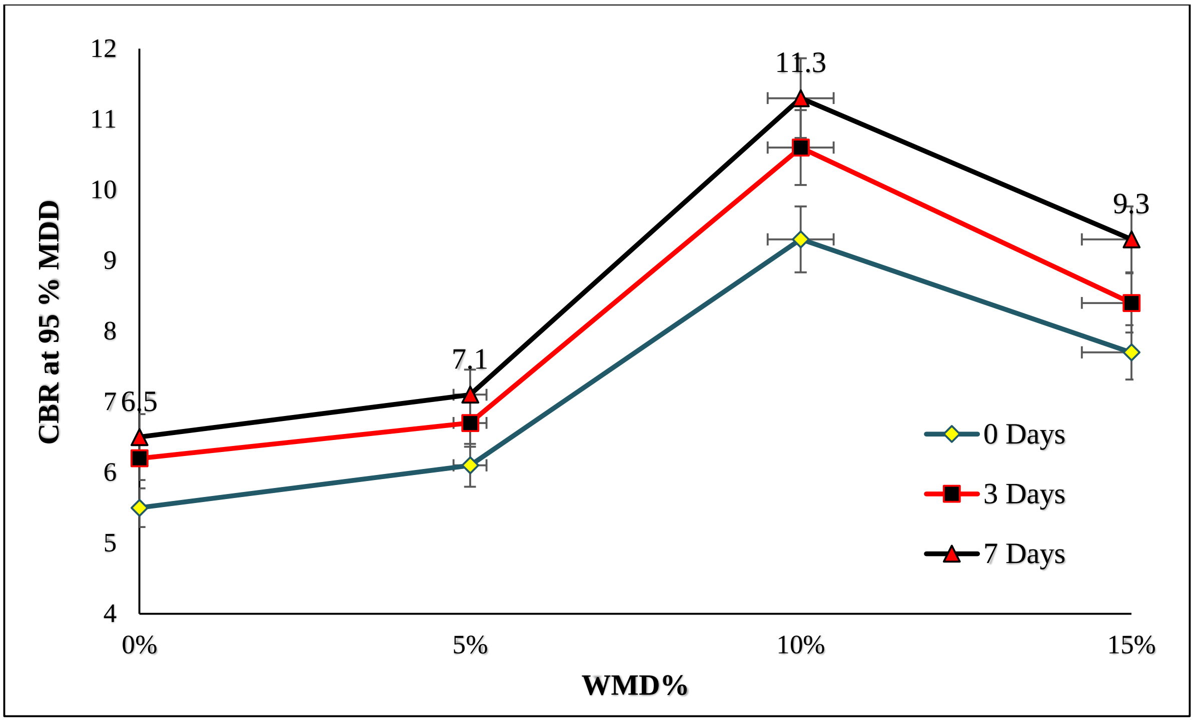

Figure 8. Unsoaked CBR values at different WMD%

The individual CBR values of unsoaked samples prepared with 10, 30, and 65 blows after 0, 3, and 7 days of healing with the addition of 0, 5, 10, and 15% WMD are shown in Figures 9 to 12, respectively. CBR values obtained at 95% MDD are also shown in the figures. The effect of the healing period, compactive effort, and WMD on the CBR values are also depicted. CBR values are improved with increased healing period and WMD% till 10% addition.

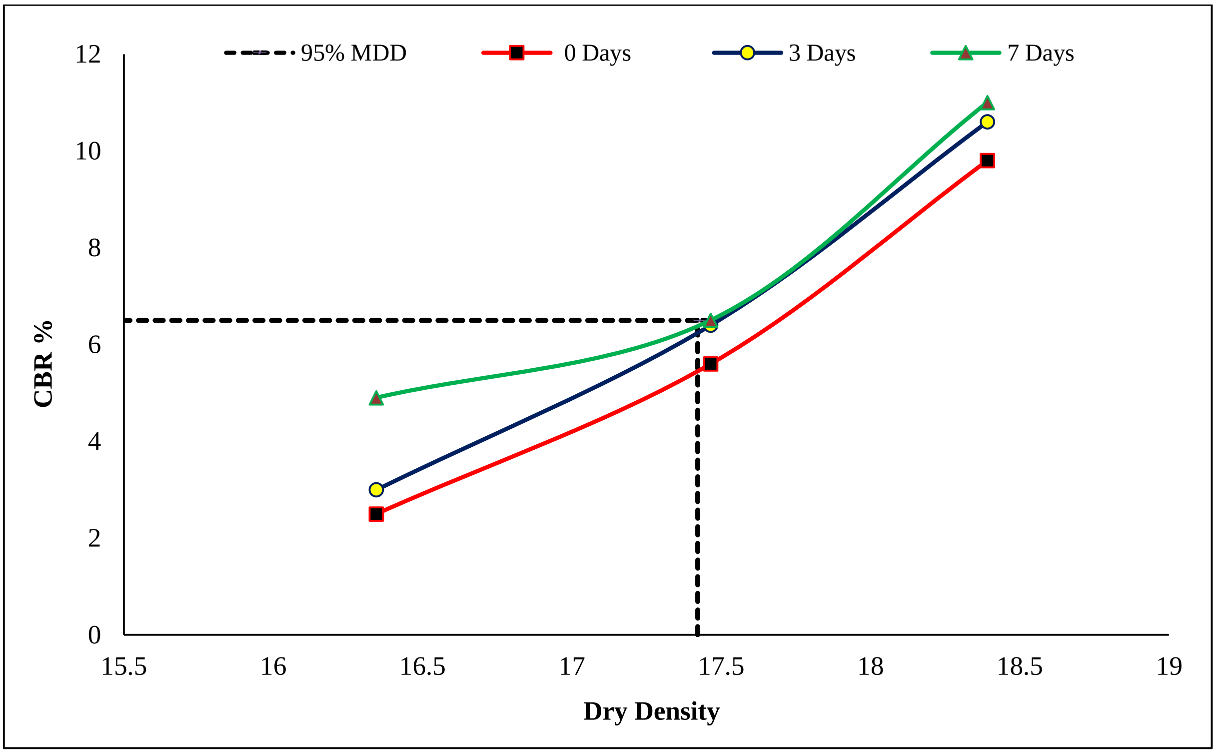

Figure 9. CBR value at 0% WMD

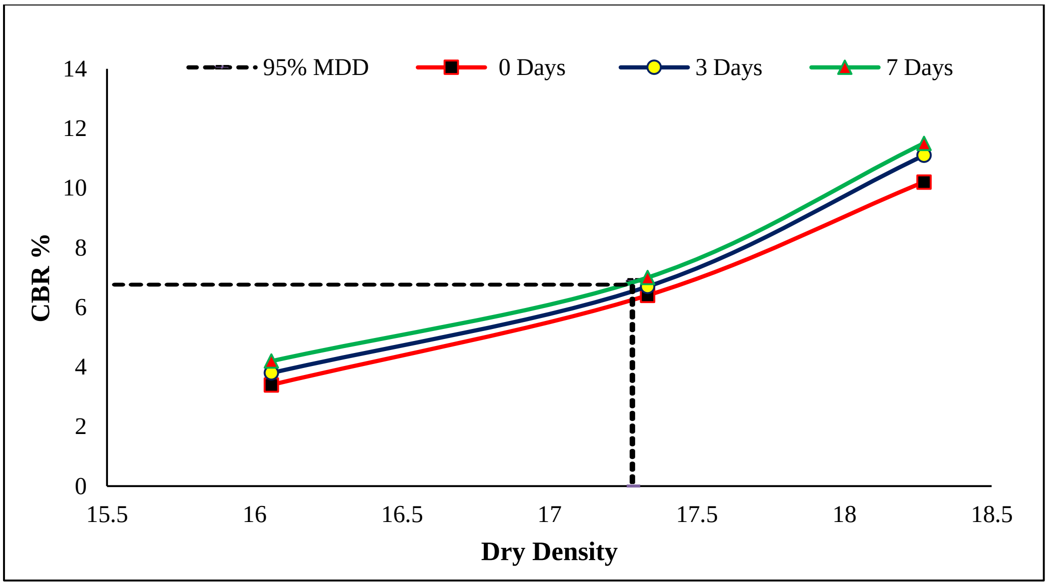

Figure 10. CBR value at 5% WMD

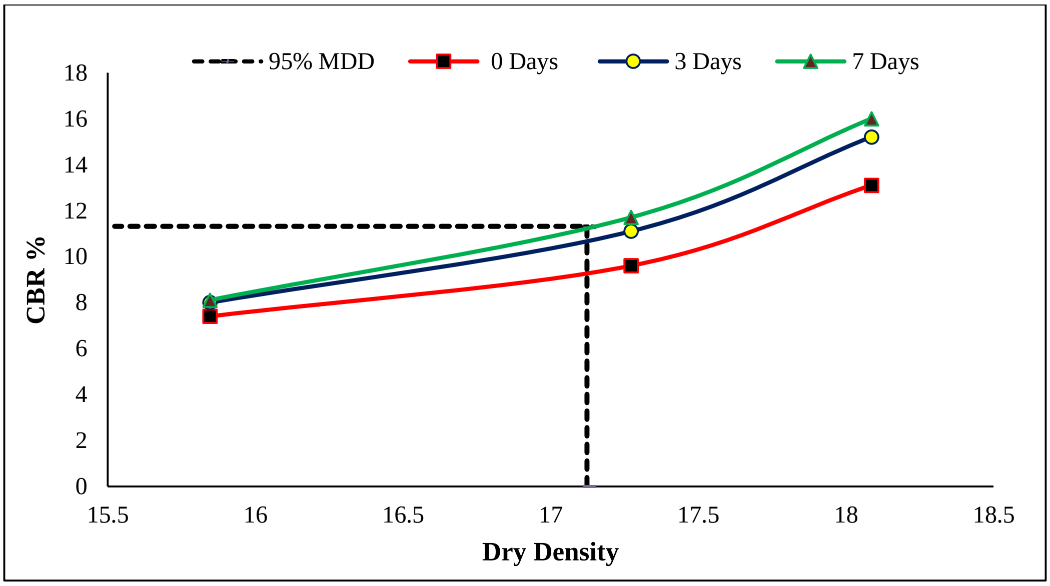

Figure 11. CBR value at 10% WMD

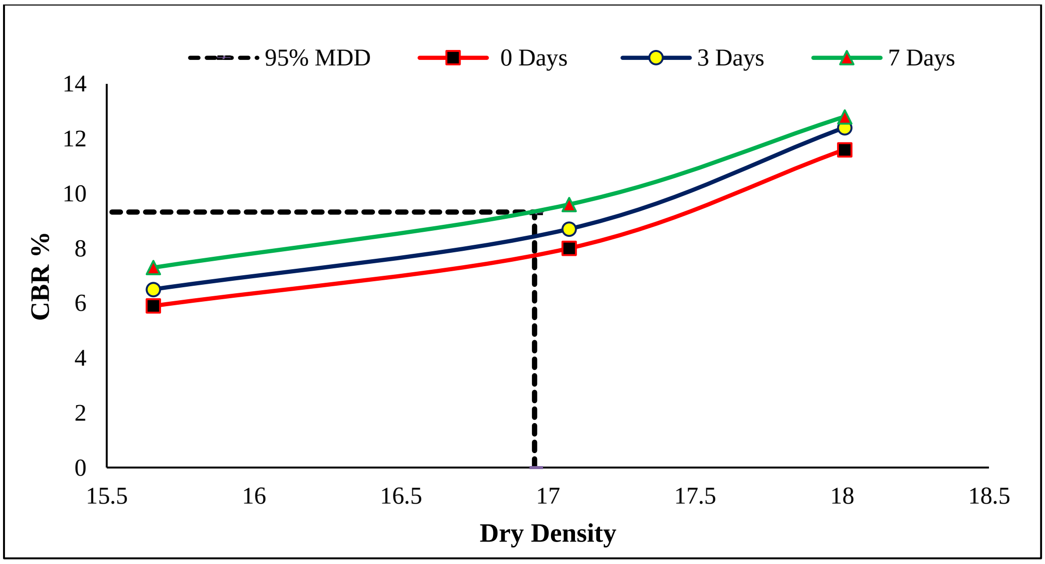

Figure 12. CBR value at 15% WMD

4.5. Soaked CBR

The results of soaked CBR specimens after 96 hours of soaking are shown in Figure 13. Effect of compactive effort (10, 30, and 65 blows) with WMD% shows the maximum value obtained at 10% addition of WMD. Figure 14 presents a comparative analysis of the effect of WMD% on the unsoaked and soaked CBR values at 95% MDD. Unsoaked CBR values with different healing times have been displayed in the figure. The maximum value of CBR in both conditions has been obtained at 10% WMD; on the other hand, it is clear that the healing period has increased the CBR strength of stabilized soil. Similar trends have been obtained by Sabat et al. (2015) [46], where CBR values were maximum at 9% addition of marble dust, and it has been endorsed by Pastor et al. (2019) [47]. The reason for the CBR values trend is the same as for UCS and swell potential values.

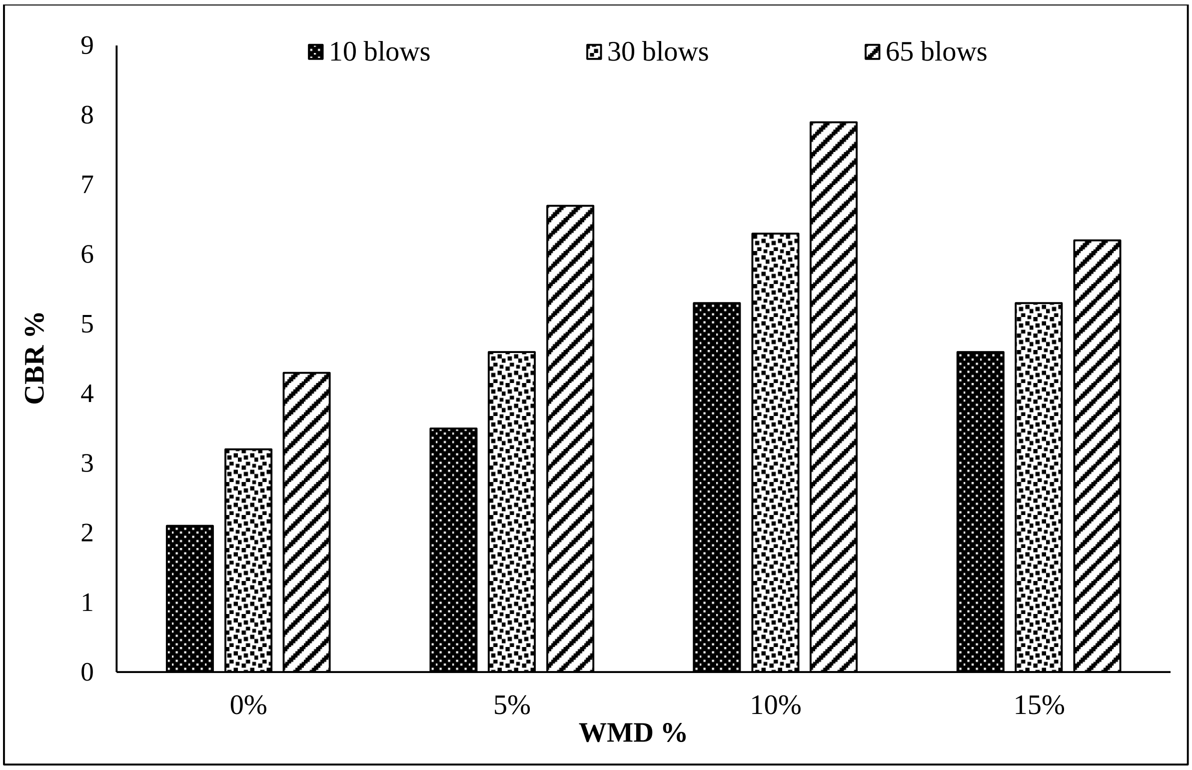

Figure 13.1 Soaked CBR values at different WMD%

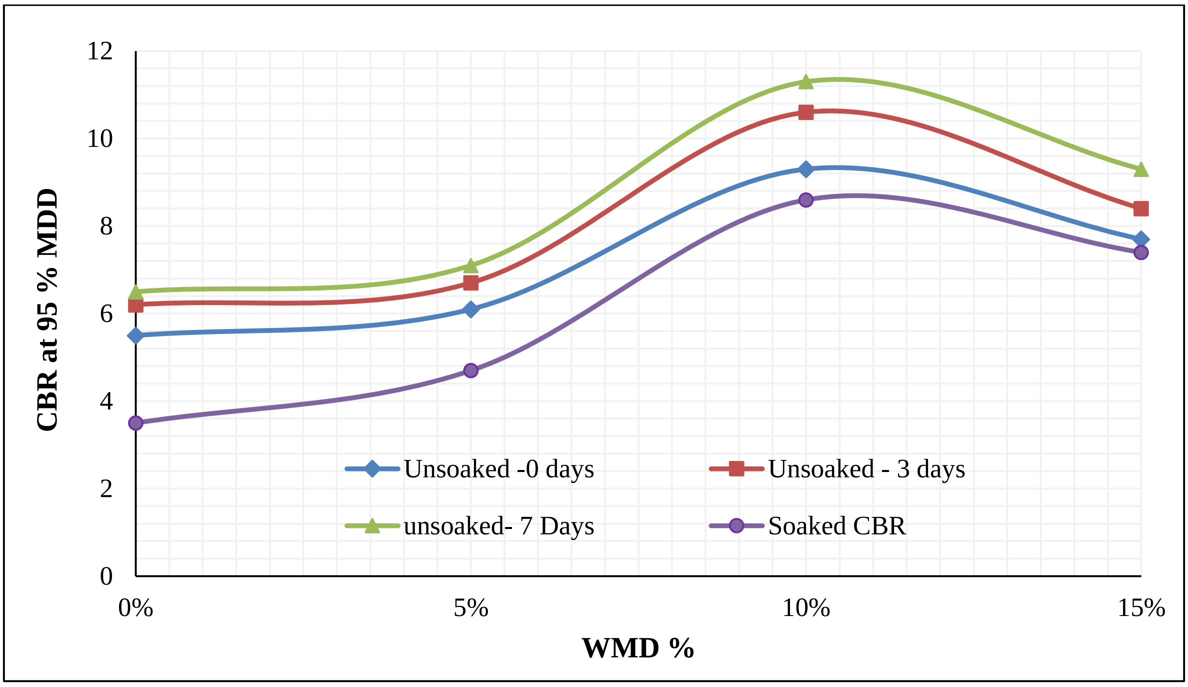

Figure 14. Soaked and Unsoaked CBR values with different WMD%

5. Conclusions

The effectiveness of WMD as a stabilizer to increase the physio-chemical properties of CL-ML soil has been studied by performing a series of laboratory tests. The properties of soil samples were evaluated without and with the addition of 5, 10, and 15% WMD by weight of the soil samples. Conclusions deduced from the study are as follows:

- Ten percent (10%) dosage of WMD has been identified as an optimum content for the target soil improvement. The results presented in the previous section depict the improvement of all the studied parameters at 10 % WMD content.
- The mixing of WMD with the collapsible soil decreases MDD while the OMC increased for all WMD dosages. The decrease in soil's dry density by the addition of waste marble dust is due to the low specific gravity of waste marble dust, mechanical action, and increased water affinity.
- The UCS of the soil increased up to 10% addition of WMD. Further addition of WMD decreased the strength of the soil. On average 100% increase in UCS of the virgin soil was observed. This was due to the densification of particles, and hence it gives more strength to the soil.
- The CBR value demonstrated an increase from 8.5 to 12% and 9.8 to 13.1 with a 10% dosage of WMD at 2.5- and 5-mm penetration, respectively. The percentage increase in CBR value without curing was acquired as 41.18% and 33.67% for 65 blows at 2.5- and 5-mm penetration, respectively. The maximum CBR value was obtained as 16% at seven days curing period. Further addition of WMD reduces the CBR value.
- The maximum improvement of soaked CBR was also attained at a 10% dosage of WMD. It has improved 12% and 22.4% for 65 blows at 2.5- and 5-mm penetration, respectively.
- The stabilization of collapsible soil using an abundantly available waste material (WMD) presents an environment-friendly process from biological, technical, and economical perspectives. The soil mainly improved due to the physio-chemical processes, including blending, densification, and cation exchange reactions.

6. Declarations

6.1. Author Contributions

Conceptualization, A.W. and M.U.A; methodology, A.W.; validation, M.U.A., and S.S.S.G.; formal analysis, R.A.K.; investigation, M.U.A.; resources, A.W.; data curation, R.A.K.; writing—original draft preparation, R.A.K.; writing—review and editing, R.A.K; supervision, S.S.S.G.; project administration, M.U.A. All authors have read and agreed to the published version of the manuscript.

6.2. Data Availability Statement

The data presented in this study are available in article.

6.3. Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

6.4. Conflicts of Interest

The authors declare no conflict of interest.

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