A comparative study: improving soil dry compaction through granular material addition versus increased compaction energy

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ABSTRACT: In arid and semi-arid regions, compaction is challenged by water scarcity and high transport costs. One proposed solution is to increase the compaction energy. However, this strategy can be replaced by the addition of coarse materials to increase soil compaction where possible. This study analyses and compares the effectiveness of increasing compaction energy and adding coarse materials, such as gravel, to fine-grained soils. The research includes compacting soils at both optimum and low water content levels to assess their effect on the maximum dry density and bearing capacity of the soil under investigation.

Keywords: Dry compaction; Fine-grained soil; Maximum dry density; Energy level; Gravel material.

1 INTRODUCTION

In arid regions, water is scarce and barely used by the people who live there. To boost economic activity in the south, road, rail, and air infrastructure must be built. Compaction work in these regions is hampered by the unavailability of water. To this end, researches have been carried out with the aim of proposing water-saving compaction methods. As a result, increasing the compaction energy has proved to be one of the solutions that have given good results; Numerous studies have explored the impact of compaction energy on fine-grained soils, employing energy levels ranging from 15 to 30 blows per three to five layers to investigate the compaction of cohesive soils at both dry and wet sides of the optimum water content [1].

Previous literature study indicates that increasingcompaction energy relates with a proportional rise inmaximum dry density (MDD), alongside a decrease in optimum moisture content (OMC) and improved California Bearing Ratio (CBR) values [2]. For instance, on stabilized fine soil, an increase in compaction energy from 611 to 2279 KJ/m^3 led to an inversely proportional relationship between MDD and OMC, resulting in a 10% gain in MDD and an 8% reduction in water content [3 and 4].Field experiments conducted in Sudan's arid regions evaluated dry compaction for road construction, demonstrating satisfactory embankment performancedespite utilizing soil at a natural moisture content 20% lower than the Proctor Optimum Moisture Content (OMC). Additionally, studies investigating the effect of varying compaction efforts on the engineering propertiesof fine soils underscored significant enhancements insoil properties, particularly when compacting at higher energy levels [5].

The improvement of compaction conditions can be done with the addition of granular materials. Crushed granite was added to lateritic fine soil with different percentages. It is observed that the optimal water content decreased with the increase of the amount of the additive. The soaked CBR values increased from 14 to 37% with the addition of 20 to 30% [6]. Marginal soil was stabilized mechanically by the addition of gravels with sand or crushed stones with sand. It can be showed that the CBR values were improved by the addition of gravel from 15% to 20%; and for crushed stones from 12% to 15% [7]. Compaction tests and bearing capacity of tuff and quarry dust mixture showed the decreases of OMC and the increase of MDD. The bearing capacity indexes indicates that the optimal addition of quarry dust is equivalent to 30% for the immediate indexes and 40% for the soaked indexes after 4 days [8].

The present work aims to improve soil compaction at low water content through a series of laboratory tests such as proctor and CBR tests. At first, the influence of increasing energy level at low water content is studied on silty sand soil, in another hand the effect of the addition of grained material on this silty sand at the lowest water content near the natural moisture content was done. A comparison of the effect of the two methods was analyzed on the MDD and bearing capacity.

2 MATERIALS AND METHODS

2.1 Materials

The materials underwent a series of physical tests as sieve analysis (NF P094-056 and NF P094- 057), Atterberg's limits (NF P094-051), and specific gravity (G). According to USCS standards, the soil was classified as fine well-graded silty sand, while the gravel is classified as well-graded clean gravel.

The silty sand was extracted from Jijel by *SOALKA Company* in the northern east of Algeria, this soil has a similar characteristic to the soil existing in the arid regions. The soil composition contained 38.2% silts and 43.3% sand, with minor proportions of clay and gravel. The soil exhibited aplasticity index of 11.25% and a liquid limit of 39.80%. The soil physical parameters are presented in the Table 1.

The gravel material was from a local supplier according to its granular classes (0/3) and (3/8) and its angular shape. Gravel properties are presented in Table 1. The sieve analysis for both natural soil and gravel is presented in Figure 1. This material is used as an additive.

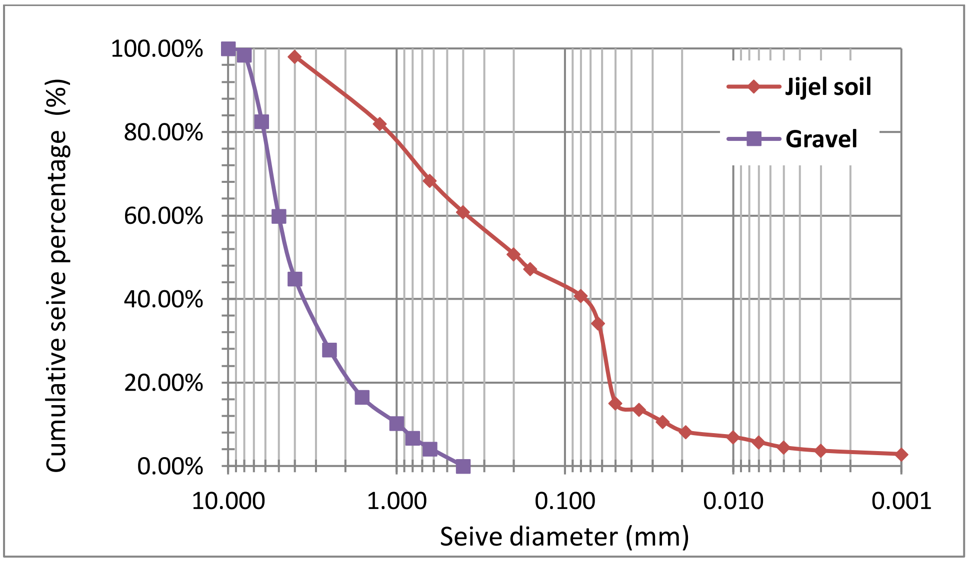

Figure 1- Sieve analysis curve of studied soil.

Table1.Soil and gravel physical properties

Parameter	soil	Gravel
Specific gravity	2.65	2.7
Gravel (%)	15.4	78
Sand (%)	43.3	15.2
Silt (%)	38.2	6.8
Clay (%)	3.1	-
Uniformity coefficient (Cu)	15.38	5
Coefficient gradation (Cc)	0.34	1.8
BMV	0,53	-
Natural moisture content (%)	7,83%	-
Liquid Limit LL (%)	39,80%	-
Plasticity Limit PL (%)	28,55%	-
Plasticity Index PI (%)	11,25%	-

2.2 *Methods*

2.2.1 *Effect of compaction energy*

The present research is a laboratory study, affected on a silty sand.
The influence of compaction energy was studied on soil specimens that where compacted using a Proctor mold with different compaction energy as shown Table 2. Each specimen underwent compaction of three to five layers, with 25, 56 and 95 blows per layer using 2,5 kg and 4.5 kg hammers.

Table 2. Different compaction energy levels

Energy levels	Blows /layer	Compaction Energy (kJ/m3)
E1	25	588
E2	56	1300
E3	25	2660
E4	56	5960
E5	95	10120

2.2.2 *Effect of gravel addition on soil compaction parameters*

The process of adding the different amounts of gravelwas done by a path of 5% to the natural soil by dry weight. The compaction was achieved using a Proctor and CBR mold with modified compaction energy. The California Bearing Ratio (CBR) test was conducted immediately after compaction to assess the immediate Californian bearing index according to French standards NF P94- 078.

3 RESULTS AND DISCUSSIONS

3.1 *Effect of compaction energy*

Figure 2 showed the impactof energy levels on the relationship between soil dry density and moisture content. The overall shape of the compaction exhibits irregularity, resembling those examined in prior studies [5] and [9], which is particularly significant for analyzing dry compaction characteristics.
Notably, lower dry densities are achieved at lower energy levels, whereas the maximum dry density is attained at the highest energy level. The enhancement in maximum dry density amounts is about 19%, increasing from 16.73 kN/m^3 to 19.84 kN/m^3 for energy levels ranging from E1 to E5, respectively. This increase in compaction energy and maximum dry density correlates with a decrease in optimum moisture content by about 38% (from 15.85% to 9.65%),

as depicted in Figure 3. As compaction energy progresses, the values of optimum moisture content decrease significantly due to the reduction in air voids within the soil. This phenomenon results in a closer rearrangement of soil particles, thus reducing the capacity of voids to retain water, The same result was found by [2, 3 and 6].

At low water content (2% and 4%), the obtained MDD at E5 was high (>15%) than those observed at the OPM with E1 and E2. The higher energy level offers the possibility of accessing the MDD recorded at the OPM.

The saturation curves showed that the soil saturation is less than 60%, at low water content (2% and 4%). At OPM, the soil saturation is less than 80% and the wet side is parallel to the curve of S=100%, referring to a well-done compaction.

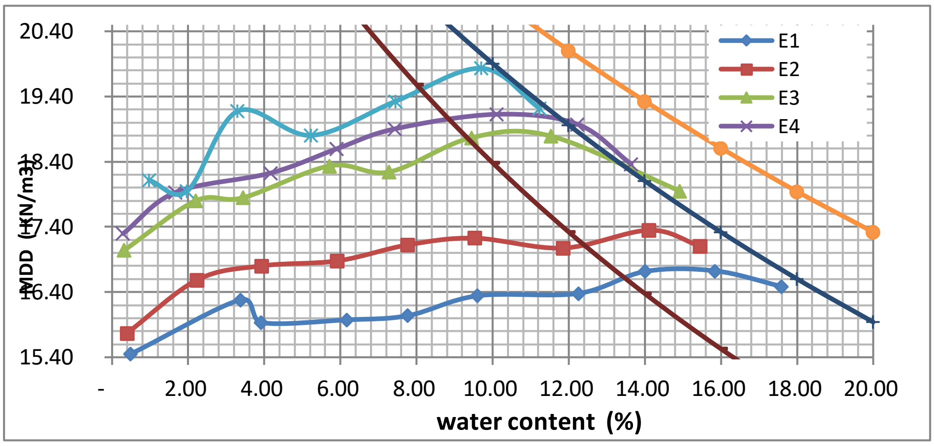

Figure 2: The influence of progressive energy onthe maximum dry density

3.2 Effect of gravel addition

Various amounts of gravel were added to the silty sand by dry weight (5%, 15%, 20%, and 25%). The admixtures were compacted at 4% of water content, and the dry density was measured as shown in Figure 3. From this figure, the MDD increase proportionally with the addition of gravel. The admixture of 25% presented a high value of MDD (18.52 kN/m^3), it was about 9% of growth. This behavior is due to the specific gravity of gravel which is higher than of the silty sand.

The MDD of studied soil is 18.47 kN/m^3 obtained at OMC. It was noticed that even though the low moisture content (4%), the MDD values of 18.38 kN/m^3 and 18.52 kN/m^3 respectively for 20% and 25% of gravel addition were close to that obtained at the OMC with no gravel addition. This result show that the addition of gravel is well effective when compacting at low water content.

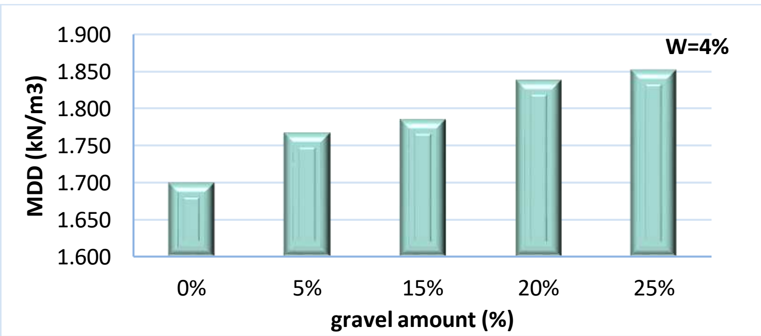

Figure 3 – The evolution of maximum dry density at 4% ofwater content as function as gravel content.

The CBR value measured at low water content (4%) underwent a decrease of about 30%. With the addition of gravel, the CBR values rose to 30.7 at the addition of 25 %, this growth was about 26%. The results of CBR tests are presented in Figure 4.
According to Figures 3 and 4, it can be considered that the amount of **25%** of gravel addition was an optimal gravel content. This optimal amount strengthens the soil structure by providing a more rigidstructure, that contributes to improve the soil's bearing capacity. The CBR results are in concordance with the MDD results obtained at compaction tests. Similar results were found [10].

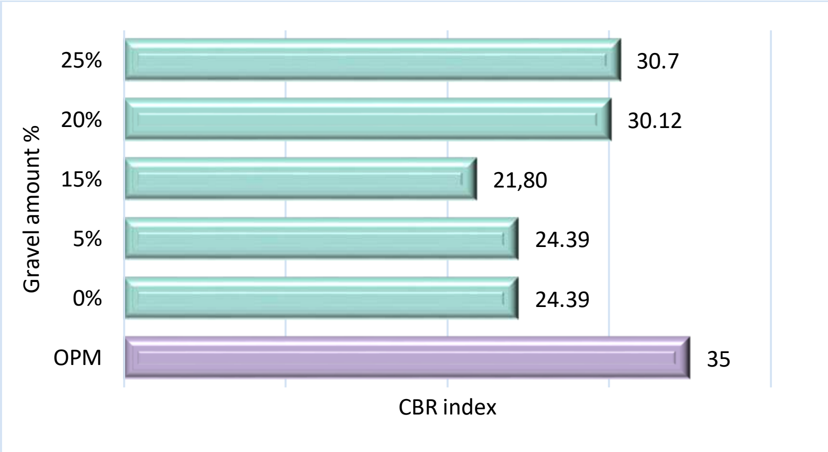

Figure 4 – The evolution of CBR values at 4% of watercontent as function as gravel content.

3.3 Comparison between the effect of energy and the gravel addition

These two methods can be more effective at dry compaction, they give higher compaction densities of more than 18 kN/m^3 at high energy levels (E4 and E5) and at the optimal addition of gravel (25%), as mentioned in the figures 2 and 3. However, the use of these methods depends on their accessibility in arid areas. The addition of gravel seems to be economical where the deposit areas are approximate, it allows for saving time and reduces the cost of machinery maintenance and its energy. This assumption is done based on the MDD values but it can be approved by CBR values regarding the proportional relationship of these two parameters existing in the literature and confirmed in this paper.

4 CONCLUSIONS

This paper conducted an experimental investigation on fine silty sand soil to explore the impact of compaction energy and gravel addition at low water content conditions prevalent in the arid zones. The study yielded several key findings:

- Increasing energy levels allows us to obtain suitable densities for low water content compaction, from energies higher than of the modified proctor energy.
- The gravel addition improves the California Bearing Ratio (CBR) Index and maximum dry density (MDD) when compacting soil at 4% of water content, these values were close to those obtained at the optimum moisture content.
- The two methods analysis shows that they are effective in saving water and can be achieved according to their accessibility in site. Adding gravel when it's available appears to be more economical, environmentally, and saving time. the soil's bearing capacity can be improved by this addition while compacting with proctor modified energy

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