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Research Article

Effect of Glass Fiber Reinforced Polyesters Pipe Wastes on the Properties of Fine Grained Soils

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ABSTRACT

Industrial wastes used as additives in soils are widely applied due to their low cost and ability to prevent environmental pollution. This study investigates the effect of Glass Fiber Reinforced Polyester (GRP) pipe-cutting waste on the shear strength of fine-grained soils. This effect was evaluated for silty soils in the laboratory and clayey soils in the field. GRP was added to the clay at several ratios of cement weight using the deep mixing method at the site. The laboratory results revealed that cohesion increased up to nearly four times compared to the natural state, with the optimum GRP content determined as 2-3%. It was determined that the soil achieved maximum compaction in the laboratory and the highest resistance in the field when 3% of the waste was used. In field applications, a 3% GRP addition provided approximately a 7% increase in unconfined compressive strength. It was observed that GRP waste had a positive effect on the strength of fine-grained soils and improved the homogeneity of the soil mixture produced using the deep mixing method. The waste provides convenience during the drilling and retraction stages, increases workability, and results in a better mechanical mixture. This indicates an effective alternative additive for soil improvement in terms of strength, compressibility, and recycling through the practical use of waste in producing deep mixed columns.

1. Introduction

Nowadays, numerous techniques have been developed to enhance soil performance, aiming to maximize strength. Any treatment implemented on soils is expected not only to enhance their strength characteristics but also to be economically feasible. On the other hand, the growing world population continues to generate large amounts of waste and thus contributes to environmental pollution [1-3]. Therefore, finding sustainable ways to recycle or dispose of these wastes without harming the environment has become a pressing necessity, which is addressed within the framework of environmental laws [4]. Furthermore, decreasing reliance on natural construction materials has emphasized the necessity of recycling, since recycled waste ensures notable reductions in raw material consumption and energy use [5]. Although waste materials are widely used in concrete, the most common construction material, their use has also become a frequently researched topic in the field of soil improvement [6-9].

Among the earliest waste products employed for soil enhancement were fly ash [10-13]. Research on fly ash indicates that it enhances the strength and contributes to solving certain geotechnical challenges. Nevertheless, like other chemical stabilizers such as lime, it may also trigger the formation of undesirable compounds, depending on the soil’s chemi-mineralogical composition [14-16]. For this reason, it is becoming increasingly important to explore different wastes and utilize them in various soils [17].

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During the production of pipe sections, a considerable quantity of waste is produced when Glass Fiber Reinforced Polyester (GRP) pipes are cut and ground to the required dimensions for assembly [18]. The accumulation of a substantial amount of waste generated during pipe production has emerged as a pressing issue in recent years. Managing these large volumes of encourages consideration of its potential reuse when incorporated into construction materials, particularly soils. If applied to fine-grained soils, where it has not yet been extensively explored, this material could represent a noteworthy contribution to the literature, offering both an economical and innovative approach for improving problematic and collapsible ground conditions.

Bagriaçik et al. [19] investigated the use of GRP pipe waste, ground into powder, as an additive in sandy soils to evaluate its effect on bearing capacity. In their study, pipe powder was blended with sand at varying proportions, and shear strength parameters were obtained through direct shear testing. Results indicated that the shear strength of sand could be improved by nearly 31% compared to its original value. Although this material has mainly been incorporated into concrete, where it has shown beneficial effects, it still requires further exploration and testing for soil applications to fully assess its potential.

Deep Soil Mixing (DSM) is a technique in which binders are blended with the in-situ soil to form continuous columns for ground improvement. The method was first applied in the United States in 1954 using a single-bit drill. In Europe, its use began in Sweden in 1967 with lime-treated clay columns, after which it became widespread. Since the 1990s, modern DSM applications have been developed and standardized. Compared with other improvement methods, DSM is advantageous in terms of economy, sustainability, geotechnical efficiency, logistics, and constructability [20-22].

In engineering practice, the DSM technique is applied primarily to clays rather than coarse deposits, as it provides advantages in both practice and cost. Previous research has demonstrated that DSM columns enhance several geotechnical properties, including shear strength, compressibility, consolidation behavior, and elastic modulus [23-25]. As a sustainable improvement method, DSM enables the formation of columns incorporating stabilizing agents such as lime, cement, fly ash, and fibers. These columns are employed for various purposes, including mitigating liquefaction potential, providing support for deep excavations, improving foundation bearing capacity, and controlling settlement [26]. Nevertheless, achieving columns with sufficient uniformity and stiffness remains a key challenge, as their performance is strongly influenced by factors such as binder dosage, withdrawal rate, and mixing tool rotation. Therefore, careful regulation of soil consistency is essential to ensure a successful application and reliable performance.

This paper, which can provide a pioneering answer to the question of which soil properties can be improved with this waste, aims to dispose of these GRP pipe-cutting wastes by using them on fine-grained soils. Accordingly, the research is organized under two main sections: the first section examines the effect on silty soils through laboratory experiments, whereas in the second focuses on the impact on clayey soils with deep mixing columns prepared in situ in the field. Increasing the shear strength of the soil and the workability of the mortar used in the production, through the deep mixing approach applied as a soil improvement method is among the geotechnical expectations of the study. The study investigates experiments using GRP pipe-cutting wastes under two main headings: laboratory and field.

In laboratory experiments, natural Adapazari silts, which are well known for their liquefaction during the 1999 Kocaeli (Türkiye) earthquake, were used for improvement with GRP waste. After the physical tests of the silty samples in the natural state and those improved with GRP were performed, shear strength tests, including direct shear and unconsolidated-undrained triaxial shear tests, were carried out. The objective was to evaluate the ideal GRP mixing ratio in the laboratory and to assess the strength and stress-strain behavior of the improved samples. Within the scope of the field tests, classification and strength tests of the natural soil taken by drilling at a construction site in the Yalova province of Türkiye were carried out. Then, DSM columns were formed by adding 3, 6, and 9 % GRP waste by cement weight using the deep mixing method to the natural soil in the field.

The cores taken from these columns were subjected to uniaxial compression tests, and in this stage, the optimum ratio was determined in the field for clayey soils. In these tests, instead of investigating the overall strength of the DSM columns, the contribution of the GRP waste to column formation was evaluated in this method, where it is important to create homogeneous columns. In addition, the outcomes of the laboratory and field experiments conducted in this study were evaluated through a comparative analysis.

2. Materials and Method

2.1. Materials

2.1.1. Adapazarı silt

The Adapazarı silt used in the study is a fluvial silt formed by the sediments carried by the Sakarya River [27]. It is known for causing significant ground failures due to liquefaction during the 1999 Kocaeli earthquake [28]. Since increasing the strength of these silts is beneficial in both static and dynamic situations, they are included in the experiments. The physical properties of the silt used, as well as the grain size distribution curve, are given in Table 1 and Figure 1.

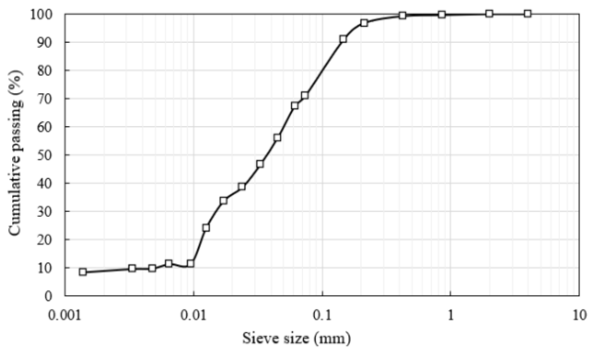

Figure 1. Particle size distribution of the silty soil

Table 1. The physical properties of Adapazari silt

Physical Property	Value
Liquid limit, w_L (%)	29
Plastic limit, w_P (%)	NP
Plasticity index, I_P (%)	NP
Specific gravity, G_s	2.70
Fine content, F_c (%)	71
Clay fraction (%)	9
Optimum moisture content, $w_{c,opt.}$ (%)	25
Maximum dry unit weight, $\gamma_{dry,max}$ (kN/m^3)	18
Soil class (TS 1500/2000, [29])	ML

2.1.2. Clayey soil

The site where the DSM column was planned to be created is located in the Yalova province. Therefore, the clayey soil was obtained from this region and its properties are provided in Table 2. As a result of the studies carried out in several different boreholes where the clay layer is located, it was determined that the clay layer in the region has an average unconfined compressive strength (UCS) of 637 kPa. However, in this stiff clay layer with high strength, it is difficult to form homogeneous and continuous DSM columns, which creates the need to increase the clay's workability.

Table 2. The physical and mechanical characteristics of the clayey soil

Physical Property	Value
Liquid limit, w_L (%)	69
Plastic limit, w_P (%)	24
Plasticity index, I_P (%)	45
Liquidity index, I_L (%)	0.06
Specific gravity, G_s	2.64
Fine content, Fc (%)	98
Clay fraction (%)	53
Soil class	CH
UCS, q_u (kPa)	637

2.1.3. GRP pipe cutting waste

Composites are engineered by bringing together different materials so that their favorable properties are combined, and/or by structuring them at a larger scale to achieve enhanced performance [30]. GRP pipes are used in many areas such as wastewater and clean water systems. These pipes are produced by the fiber winding method using quartz sand, glass fiber, and polyester resin. Therefore, excessive amounts of GRP pipe-cutting waste consist of dust generated during the production of additional couplings of GRP pipes and specially produced elbows for waste and clean water transportation in our country. Waste disposal is carried out in cement production factories for a fee. The GRP waste, with the properties given in Table 3, used in the study was produced by Subor Pipe Ind. J. St. Tr. Co.

Figure 2 shows the image of the GRP pipes and cutting wastes leaving the factory after grinding. Various ratios of polyester, resin, sand, and fiber are used in the GRP pipes produced by the company [18].

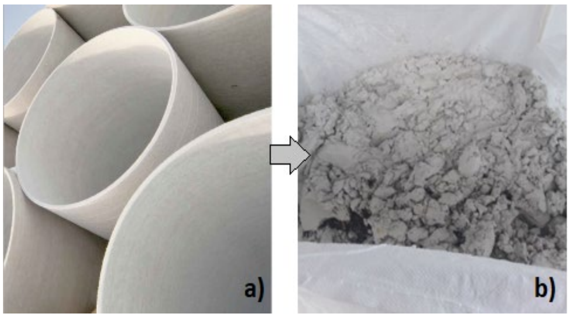

Figure 2. State of a) GRP pipes b) Ex-factory GRP cutting wastes in milled

Table 3. The characteristics of GRP waste used in the study

Property	Value
Diameter (mm)	0.2 - 4
Liquid limit, w_L (%)	49
Plastic limit, w_P (%)	NP
Plasticity index, I_P (%)	NP
Young modulus (GPa)	52 - 87
Specific gravity, G_s	2.70

2.2. Methods

2.2.1. Laboratory studies

First of all, plastic limit, liquid limit, specific gravity, sieve analysis, and hydrometer experiments were carried out within the scope of the physical experiments of GRP-added samples to determine the characteristics of the samples. Specific gravity, grain size distribution, compaction properties, and consistency limit values were determined after obtaining homogeneous samples by mixing GRP with silty soil at ratios of 1, 2, 3, 4, and 5% in the laboratory. Physical experiments were carried out in accordance with TS 1900/2006-1 [31] and classified according to TS 1500/2000 [29] standards. To determine the most favorable compaction conditions, standard compaction tests were conducted to establish the optimum water content and maximum dry unit weight of the classified samples. The test samples created within the scope of the physical experiments are as follows: Mixtures were obtained by adding natural silt (N_lab) GRP waste (GRP) in percentages of 1 (1GRP), 2 (2GRP), 3 (3GRP), 4 (4GRP) and 5 (5GRP) by the dry weight of the silt.

In the secondary stage of the laboratory experiments, direct shear [32] and triaxial shear tests [33] were applied to the samples prepared based on the compaction data to obtain shear strength parameters. In the direct shear tests, the square samples prepared with dimensions of 60 × 60 × 25 mm were sheared at a constant speed of 0.5 mm/min under 50, 100, and 200 kPa normal stresses. Since the direct shear test instrument is digital, the horizontal and vertical displacements were measured with the help of a micrometer after the shearing rate was adjusted. For the unconsolidated undrained (UU) triaxial experiments, samples were prepared with a diameter of 35 mm and a height of 70 mm from the compressed material prepared similarly to the direct shear test samples. The unconsolidated samples were sheared under confining pressures of 50, 100, 150, and 200 kPa under undrained conditions. The specimens used in both tests can be visualized in Figure 3.

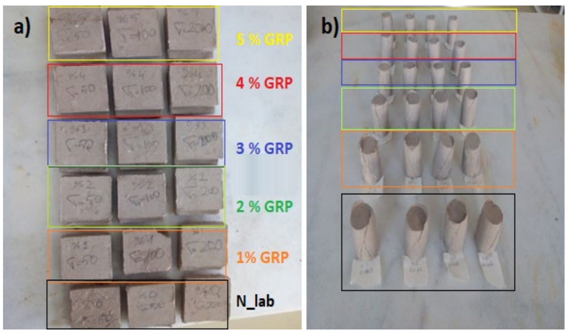

Figure 3. Tested specimens of a) Direct shear test b) UU Triaxial test

2.2.2. Field studies

The field study was carried out at a construction site in the Yalova province, where the unconfined compressive strength (UCS) of the natural clayey samples taken from the field had an average value of 637 kPa. The purpose of this process was to form DSM columns by mixing GRP waste with this clayey layer. For this purpose, a column was formed by mixing GRP waste with the soil using the DSM method at a certain point.

In the course of the field investigations, DSM columns were constructed in situ by applying the deep soil mixing method, and GRP pipe-cutting wastes were added at rates of 0, 3, 6, and 9% by weight relative to the cement injection. In the field experiments, a fixed injection parameter was chosen to provide the same dosage and volume of injection to each column. It was aimed to create DSM columns with a dosage of 400 kg/m^3, a water/cement ratio of 1/1, and a diameter of 80 cm. An auger drill with a diameter of 80 cm was attached to the machine because mixing production was to be carried out mechanically. The column lengths in the experiment were set at 3 meters. The images of the DSM method applied in column formation are shown in Figure 4.

After 27 days, cores were taken from the DSM columns formed by the double tube method and sent to the laboratory for shear testing. The visuals of the core boxes taken from the DSM column and one of the sheared samples are shown in Figure 5a and Figure 5b, respectively. This sheared (tested) sample in Figure 5b was taken from the core sample illustrated by the yellow rectangle in Figure 5a.

Figure 4. a) Application of DSM method b) The field after DSM columns are created

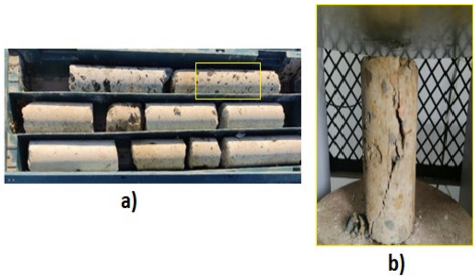

Figure 5. a) Cores taken from DSM column b) The tested core sample

3. Results and Discussions

3.1. Results of the laboratory tests

Experiments conducted in the laboratory indicate that the physical properties of silty samples with GRP pipe waste additives change, as shown in Table 4. With no significant changes observed, a slight increase in the liquid limit and a slight decrease in the specific gravity were evident.

Table 4. The physical characteristics of GRP mixed silty soils

Code	G_s	w_L (%)	w_P (%)	$w_{c,opt}$ (%)	$\gamma_{dry,\,max}$ (kN/m^3)	Soil
N_Lab	2.7	29	NP	25	18.0	ML
1GRP	2.7	29	NP	12	18.0	ML
2GRP	2.7	29	NP	14	18.1	ML
3GRP	2.7	30	NP	14	18.4	ML
4GRP	2.6	30	NP	14	17.8	ML
5GRP	2.6	31	NP	15	17.6	ML

Figure 6 shows the grain size distribution curves obtained from the sieve analysis and hydrometer experiments. As can be seen, the grain size distributions of the waste and fine-grained silt do not differ much, indicating that the particle size properties maintain their natural state.

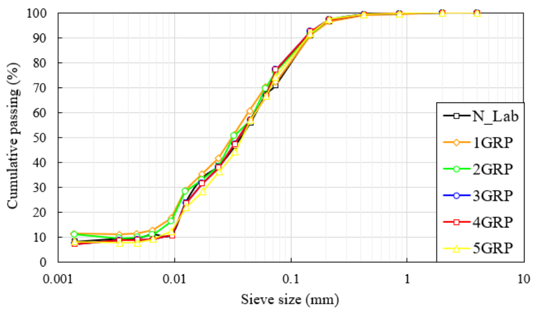

Figure 6. Grain size distribution of the natural and GRP mixed silt

Figure 7 and Figure 8 illustrate the results of the direct shear tests conducted on both natural silt and silt samples mixed with GRP. The failure envelopes of the specimens obtained from the direct shear tests are given in Figure 7. Figure 8 shows the changes in cohesion and the internal friction angle. From Figure 8a, it can be observed that the cohesion value first decreases slightly at 1 % GRP content, then reaches its maximum at 2 %, and subsequently decreases with further addition of the waste. Likewise, the increase in the internal friction angle with the addition of waste is also seen in Figure 8b, except for the waste amount of 1%. It can be observed from these graphs that while the cohesion value increases up to 26 kPa when 2% GRP pipe-cutting waste is added, the internal friction angle reaches its lowest value (29˚) at the same proportion. Similarly, while the internal friction angle attains its maximum value (36˚) at 1% GRP content, cohesion tends to decrease to its minimum (as low as 2 kPa) at the same content. Compared to the natural state, the cohesion shows an average fourfold increase with this waste; one can see that the rate of increase in the internal friction angle is not that significant. If this is the case, then it becomes evident that an appreciable focus may be given to cohesion while stabilizing soils with such waste material.

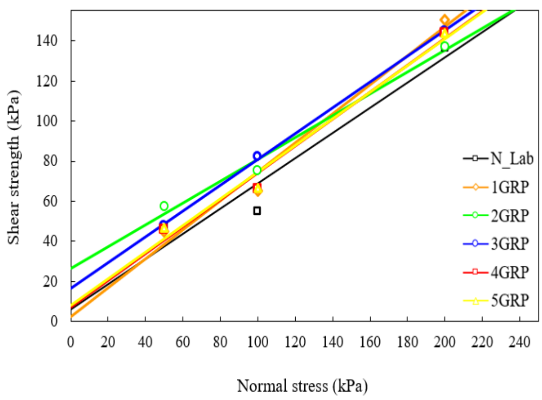

Figure 7. Failure envelopes of the specimens from direct shear test

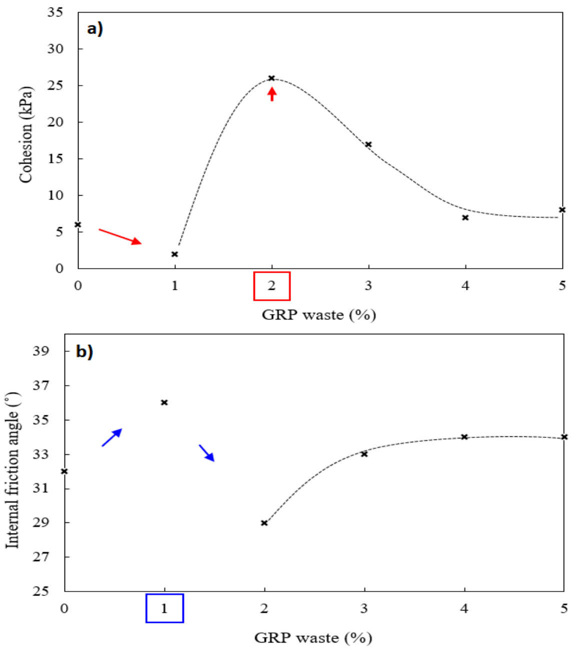

Figure 8. Change in shear strength parameters; a) cohesion, b) internal friction angle

It was understood that the dominant shear strength parameter responsible for the change in behavior was cohesion. Therefore, unconsolidated-undrained (UU) triaxial tests were carried out to continue the evaluations based on this, where undrained shear resistance was measured. Before loading, the specimens were fully saturated to ensure undrained conditions. In the UU triaxial analysis, the internal friction angle was assumed to be zero, as this test type primarily reflects the undrained shear strength of cohesive soils and the contribution of friction is considered negligible under short-term, undrained loading conditions. The UU tests were carried out under confining pressures of 50, 100, 150, and 200 kPa at a rate of 0.8 mm/min, and the average undrained shear strength was obtained as a result of the tests. Figure 9 shows the results of the UU tests in relation to the waste content.

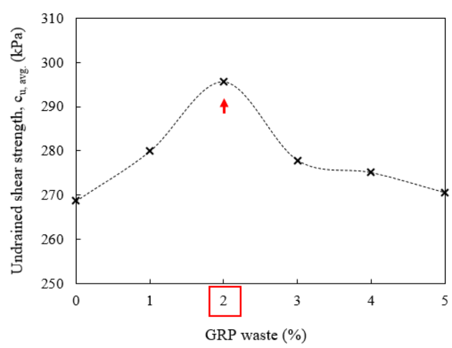

Figure 9. Change in average undrained shear strength in UU tests

In the UU test, the cohesion value increases by up to 2% in the CTP-added sample, similar to direct shear test tests. The cohesion value decreased in the test samples added after 2% of the GRP pipe-cutting waste, and an increase was observed compared to 4% in the test sample added at the rate of 5%. On the other hand, the shear strength tends to remain unchanged in the following ratios.

3.2. Results of the field tests

DSM columns were formed in the field by injecting cement into the clay layer having an average unconfined compressive strength of 637 kPa. The unconfined compressive strength test results of the cores taken from the columns constructed by the deep mixing method are given in Figure 10. As a result of the field studies, it was determined that the UCS of the DSM columns formed by cement injection alone reached up to 6.98 MPa. In contrast, the UCS values of the columns incorporating GRP pipe-cutting waste were 7.46 MPa at 3%, 6.04 MPa at 6%, and 5.00 MPa at 9% addition.

According to the graph in Figure 10, adding this waste at an amount that corresponds to approximately 3% results in an almost 7% increase in strength; then it tends to decrease and stabilize. It has also been observed from in-situ tests that as the ratio of GRP pipe-cutting waste increases, the specific gravity of the cement mortar decreases, and the time required to reach the final depth of the soil is shortened. Therefore, even if GRP pipe-cutting waste did not show very high increases in strength, the workability of the columns in the manufacturing process was changed positively.

Although the maximum strength did not reach very high levels, its advantage in creating the column by improving its workability needs to be taken into account. Under these circumstances, it may be concluded that the problem can be solved using this waste in cases where the continuous production of DSM columns cannot be achieved. In such situations, the use of GRP waste contributes to improving the workability and continuity of the DSM column construction process. In terms of addressing this significant problem that may occur in the field during the creation of DSM columns, GRP waste has the potential to gain importance according to the test results obtained from this study. Furthermore, the study also provides guidance on the ease of DSM applications in the field.

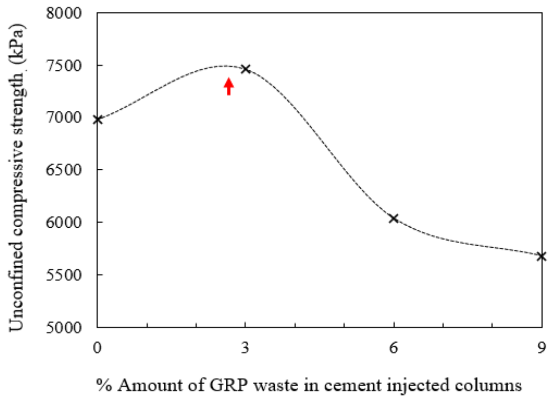

Figure 10. Change in UCS in the field

4. Conclusions

In this study, a methodological proposal is presented for the improvement of geotechnically inadequate soils resulting from increasing population, rapidly expanding urbanization, growing demands for structures, and the efficiency of the method for fine-grained soils is evaluated in the laboratory and in the field. The fact that the remediation material used in the study is a waste makes the issue particularly important in eliminating environmental pollution. The results of the tests indicated that the effect of GRP pipe cutting waste on the soil shear strength and the workability of the columns in the manufacturing process was investigated using the deep mixing method, a technique classified among soil improvement techniques. The study was examined under two main headings: laboratory and field experiments.

In laboratory experiments, natural silt samples were taken, and GRP pipe-cutting waste was added to this soil unit, and the natural state and physical properties of the mixtures were determined. In addition, the shear strength behavior of the specimens was assessed through direct shear and unconsolidated–undrained triaxial compression tests. Among the GRP-added samples, the sample with the highest strength was obtained in the direct shear tests at 2% waste for cohesion and 1% for the internal friction angle due to its water absorption characteristics. As observed in the compaction test, the high optimum water content of the GRP pipe-cutting waste supports this. These parameters show an increase followed by a subsequent decrease. Additionally, in triaxial tests, the undrained shear strength parameter was found to be almost the same but reached a peak at 2% GRP.

Within the scope of the field experiments, the classification and unconfined compressive compression strength of the clayey soil in the area where the column was formed were obtained at the construction site. Then, DSM columns were formed by injecting cement both with and without GRP pipe-cutting waste. When the samples taken from the columns were tested, it was observed that the highest strength was achieved in the column formed by adding approximately 3% of GRP waste by the weight of cement, and this column provided an improvement of about 7% compared to the DSM column formed using only cement injection. Since the GRP pipe-cutting waste has a lower unit weight than the soil, the density of the resulting mixture decreased, and the material was mixed more efficiently. In this case, it provides more uniform diffusion for the cement injection and contributes to increasing its strength. The slight decrease in the density of the injection mixture may contribute to a minor improvement in workability during the drilling and retraction stages.

When laboratory tests and field tests were compared, it was observed that the optimum GRP content was compatible with fine-grained soils. In laboratory tests, the sample with the addition of 2% GRP pipe-cutting waste by weight of silt exhibited better performance, and in the field tests, it was observed that the highest strength was obtained when 3% of GRP pipe cutting waste was added by weight of cement. As a result of the study, it was concluded that GRP pipe-cutting waste could be utilized as an alternative material in the soil improvement process. If GRP waste is used in DSM, this material, which is costly to dispose of, can contribute to the prevention of environmental pollution by ensuring its recovery and reuse, and its economic usability will increase as it is substituted for cement.

Therefore, the findings of this study demonstrate that GRP pipe-cutting waste can function as an economical and ecofriendly stabilizer for deep soil mixing applications in fine-grained soils. Its contribution lies not only in improving soil strength and workability but also in reducing cement consumption and waste disposal costs, offering a sustainable alternative for soil improvement practice.

Article Information Form

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Author Contributions

Methodology, investigation, data curing, writing – original draft: M.S.; Conceptualization, Supervision, writing—review and editing, investigation: A.Ö.; methodology, writing—review and editing: S.S.; methodology, writing—review and editing: E.B.; writing—review and editing: E.A.

The Declaration of Conflict of Interest/ Common Interest

No conflict of interest or common interest has been declared by the authors.

Artificial Intelligence Statement

No artificial intelligence tools were used to write this article.

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