Effects of Glass-Fiber Reinforced Polymer and Waste Polypropylene Plastic Particles on Geotechnical Properties of Clayey Soils for Using Subgrade in the Pavement

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Abstract

The fine-grained soil including the problematic ones can cause many difficulties in project accomplishment. Settlement and swelling are among the problems of the fine-grained soils. The present study compared the effects of the polypropylene waste plastic (PWP) and glass fiber reinforced polymer (GFRP) on geotechnical properties of the clayey soils for the subgrade design. To this end, the PWP and GFRP were randomly mixed with the fine soils of different plasticity indexes in similar weight percentages (i.e., 0.25, 0.50, 0.75, and 1). Further, compaction, unconfined compressive, direct shear, and California bearing ratio tests were performed in both dry and saturated conditions, followed by conducting the falling head permeability test. The results showed that PWP and GFRP materials were effective in the swelling potential of the clayey soil. In other words, the swelling potential decreased by about 32% and 33% in both CH and CL samples when the PWP content increased up to 0.75% in the specimens, respectively. In addition, this potential decreased by 60% when the GFRP (0.75%) was added to the specimens. Also, bearing capacity and elastic modulus increased mixing PWP (0.75%) or GFRP (0.5%) in the clayey soils by high and low plasticity indexes. Therefore, the improved soils can be used to make a subgrade layer for the pavement.

Keywords: Subgrade, Clayey soils, Glass fiber reinforced polymer, Waste polypropylene plastic particles, Pavement.

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1. Introduction

Material preparation is considered as one of the problems in pavement construction, which is the required technical specification for use in pavement layer construction. In general, materials are obtained from the river bed or the mine. Nevertheless, this method can cause damage to the environment. Thus, improving the operations in the pavement construction area is necessary when appropriate soils and materials are not available. Different chemical or physical methods can be employed considering the type of soil. Soil reinforcement is regarded as an effective and reliable method for improving and stabilizing the soil layers in addition to increasing the load-bearing capacity and shear strength, and finally, reducing its settlement. Therefore, it is used to stabilize the subgrades, road backfilling, and pavements. Nowadays, the efficiency and ability of the soil reinforcement regarding providing the proper applicable solutions in various projects have paved the way for this method in geotechnical engineering. In addition, the production and incorporation of polymeric materials as modern materials in civil engineering have become widespread during the last three decades. Further, increasing the volume of urban wastes and materials, especially plastic waste and rubble from building destruction has created many problems in megacities. Furthermore, environmental problems due to the non-professional disposal of waste materials have attracted the researchers' attention toward their recycling. To increase the soil load-bearing capacity and its shear strength properties, the application of polypropylene and glass fibers became widespread leading to an increase in the probability of enhancing these properties in different conditions. The subgrade layer in the pavement can be a compacted embankment, natural, or an improved ground. The materials of this layer are prepared according to specific criteria and the other layers are constructed above it. Moreover, the subgrade layer is as a foundation of the pavement since all the loads of vehicle toleration rely on this layer. Therefore, making a high-quality subgrade is highly important. As mentioned above, recycled aggregates [Ayan et al., 2016], geosynthetic materials such as geotextile and glass fiber reinforced polymer (GFRP), and recycled waste materials are now used to improve the pavement layers and soils under the foundation. Several studies have focused on the field of geosynthetic application [e.g., Khabiri, 2011; Kumar Senthil and Rajkumar, 2012; Sadeghi and Dabiri, 2015; Nazari and Dabiri, 2016; Ghasemvash and Dabiri, 2019]. Similarly, various comprehensive studies have evaluated the use of polymeric fiber and the effects of the chips on the bearing capacity and geotechnical properties of different soils [e.g., Dean and Fretting, 1986; Arzenic and Chawdhury, 1988; Benson and Kayer, 1994; Ranjan et al. 1996; Michalowsky and Zoba, 1996; Andersland and Khattac, 1997; Wang, Frost, and Murray, 2000; Cai, Shi, and Tang, 2006; Erdincler and Ayhan, 2010; Sukantasokl and Jamasawang, 2012]. For example, Cristello et al. [Cristello et al. 2015] investigated the effect of soil reinforcement with separated fibers on the clayey sand soils by implementing the seismic wave propagation test. This study mainly aimed to evaluate the effects of the GFRP on the bearing capacity and shear strength of the clayey soil. Likewise, Sahebkaram and Dabiri [Sahebkaram and Dabiri 2017] compared the effects of the type application of several fibers on the soft soil and found that polypropylene further increased the bearing capacity compared to the other fibers. Figure 1 displays the materials and methods that were used in the above-mentioned study. Additionally, Asadollahi and Dabiri [Asadollahi and Dabiri 2017] studied the impacts of the GFRP on the improvement of the clayey soil in Tabriz. The results demonstrated that mixing GFRP up to 0.8% led to an increase in the bearing capacity of the clayey soil.

Generally, the results of previous studies indicated that the fibers can affect the geotechnical behavior of the soils although fiber properties, length, and the percentage of utilization are extremely important for soil stabilization. In the present study, the polypropylene waste plastic (PWP) was employed instead of the GFRP. In addition, a different percentage of the material presence in the soils was considered as compared to that of previous studies. Moreover, the effects of the added material on two clayey soils with different plasticity indexes (PI) were explored in terms of swelling, permeability, and bearing capacity for the preparation of the subgrade layer. The above-mentioned issues are regarded as the innovations of the present research.

2. Materials and Methods

2.1 Materials

As previously mentioned, the present study mainly aimed to compare the impact of GFRP and PWP application for improving fine-grained soils with different PI values to make the subgrade layer. Therefore, the clayey soils were obtained from Iran Khodro and Shahid Salimi Industrial Areas in Azerbaijan. The prepared specimen grading and clayey particles were selected since the soils in the study area included sand and gravel particles. Further, the grading curve of the materials was determined by using [ASTM D421] and [ASTM D422] (Figure 1). Furthermore, Atterberg limits were estimated according to [ASTM D4318-95a], followed by determining the values of specific gravity (Gs) based on the [ASTM D854]. The PH analysis of the clayey soil was also performed based on the [ASTM D4972]. As shown in Figure 1 and Table 1, the clay is in accordance with the unified classification in CH and CL groups.

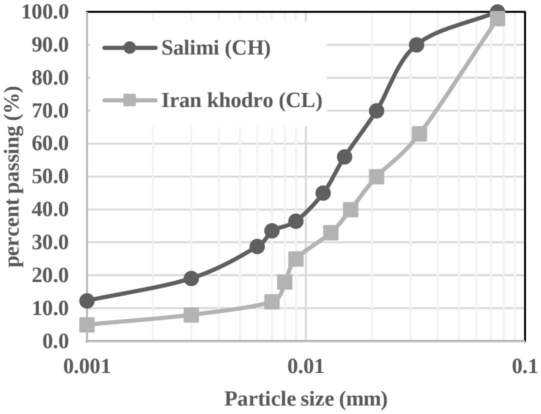


Figure 1. Grain size distribution for the used soils

Table 1. Geotechnical Properties of the Soils

Properties	Salimi (CH)	Iran Khodro Azerbaijan (CL)
PI	28	13
Gs	2.71	2.62
PH	8.17	8.05

Note. CH: Clay soils with high plasticity index; CL: Clay soils with low plasticity index; PI: Plasticity index; Gs: Specific gravity; PH: An important quantity is logarithmic, which determines the acidity or alkalinity of the material.

In the present study, the GFRP with a length of about 12 mm, was used and randomly mixed with the clayey soils in different amounts (i.e., 0.25, 0.50, 0.75, and 1%, respectively), which was obtained from commercially available materials supplied by RUSTIN RESIN Company. In addition, PWP (with sizes about 3 to 5 mm) (Figure 2a-b). The mechanical properties of the GFRP are presented in Table 2.

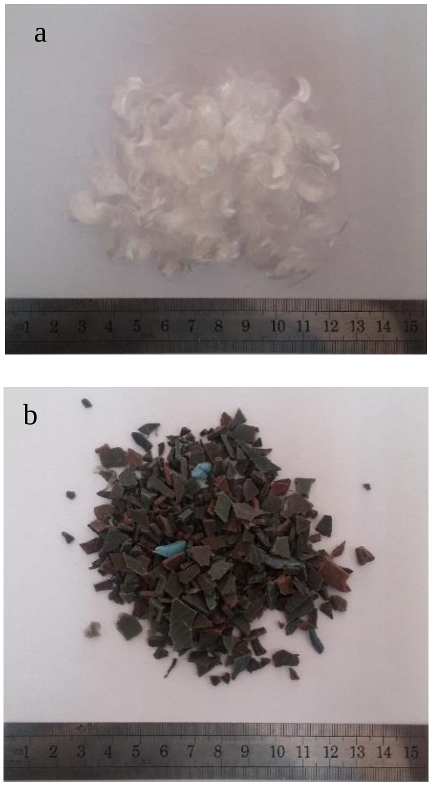


Figure 2. Image of the materials used in this study for the clayey soil improvement: (a) GFRP, (b) PWP

Table 2. Mechanical Properties of Used GFRP [Rustin Resin]

Properties	Values
Diameter	0.3 mm
Length	12 mm
Type	Glass
Colour	White
Elastic modulus	70 GPa
Gravity	9.45 kN/m^3

Note. GFRP: Glass fiber reinforced polymer**.**

2.2 Methods

The present study administered some tests in order to evaluate the geotechnical and mechanical properties of the improved soils for use in the subgrade layers. The compacted and then uniaxial compressive strength tests were performed according to the [ASTM D698] and [ASTM D2166] (Figure 3a), respectively. Then, the direct shear test was conducted based on the [ASTM D3080-11]. In this test, the specimens were prepared in 10×10 cm mold at the optimum water content (w_{opt}). In addition, loading was performed at a slow speed (0.05 mm/min) using vertical stress equals to 100, 200, and 300 kPa (Figure 3b). Next, the California bearing ratio (CBR) test was run in both dry and saturated conditions based on the [ASTM D1883]. In this test, the selected speed loading (1.27 mm/min) and CBR number were estimated in 1 inch (2.5 cm) and 2 inches (5 cm) of piston influence values. Moreover, the swelling value in the specimens was evaluated (Figure 3c-d) in a saturated condition. Ultimately, the falling head permeability test was performed according to the [ASTM D5084] to determine the effects of the added materials in the drainage and permeability of the improved soils (Figure 3e). The experimental programs are provided in Table 3. It should be noted that the study repeated 25% of the total number of the tests that were performed on the specimens.

Figure 3. Test apparatus used in the present study: (a) Uniaxial compressive strength test; (b) Direct shear test; (c) CBR test in a dry condition; (d) CBR test in a saturated condition; (e) Falling head permeability test

Table 3. Experimental Program of This Study

Total	Clay+ 1% GFRP or PWP	Clay+ 0.75% GFRP or PWP	Clay+ 0.50% GFRP or PWP	Clay+ 0.25% GFRP or PWP	Clay	Material Tests
9 series	A series in two positions	A series in two positions	A series in two positions	A series in two positions	A series	Compaction test
9 series	A series in two positions	A series in two positions	A series in two positions	A series in two positions	A series	Uniaxial compressive strength test
23 series	Three series in two positions	Three series in two positions	Three series in two positions	Three series in two positions	Three series	CBR test in saturate condition In three energy counts (i.e., 10, 25, and 56 blow)
23 series	Three series in two positions	Three series in two positions	Three series in two positions	Three series in two positions	Three series	CBR test in a dry condition In three energy counts (10, 25 and 56 blow)
9 series	A series in two positions	A series in two positions	A series in two positions	A series in two positions	A series	Direct shear test in 100, 200, and 300 kPa
9 series	A series in two positions	A series in two positions	A series in two positions	A series in two positions	A series	Head falling permeability test

Note. Positions: No.1: With GFRP; No.2: With PWP; CBR: California bearing ratio.

3. Results

3.1 Results of compaction test

The obtained results from the compaction test are displayed in Figures 4a-b and 5a-b. Generally, the maximum dry density (γ_{dmax}) in the CL was more than the γ_{dmax} value in the CH soil in an unimproved state due to fine quartz and silica grains. As shown in Figure 4a, γ_{dmax} increased in both CL (1.27%) and CH (1.81%) specimens when PWP (0.75%) was added to the specimens as compared to the unimproved condition. Based on the data, in Figure 4b, γ_{dmax} increased in both CL (2.67%) and CH (2.55%) specimens by mixing the GFRP (0.5%) with the specimens. Comparing the diagrams (Figure 6 a-b), it can be found that the GFRP was slightly more effective than the PWP. As regards PH values in Table 1, the clayey soils in the studied areas were alkaline and limy. Therefore, the chemical reaction between lime-clay particles and fine cemented formation made a new structure with bigger particles. As a result, locating PWP (0.75%) and GFRP (0.5%) between the voids of the existing structure can make a strongly improved soil although this trend is not consistent with the findings of Asadollahi and Dabiri (2017). Moreover, according to Figure 5a, the w_{opt} decreased up to 2.45% and 7.69% in CH and CL specimens by mixing the PWP (0.75%), respectively. Contrarily, the presence of the GFRP in the specimens generally increased the w_{opt} (Figure 5b), which is in line with findings of Asadollahi and Dabiri [Asadollahi and Dabiri , 2017] research.

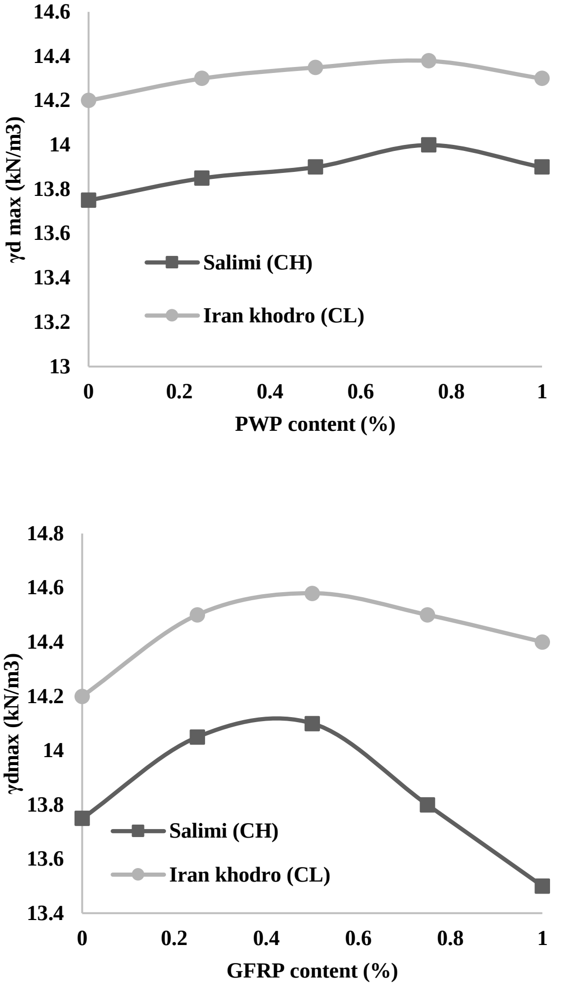


Figure 4. Effects of the mixed materials on maximum dry density: (a) PWP content; (b) GFRP content.

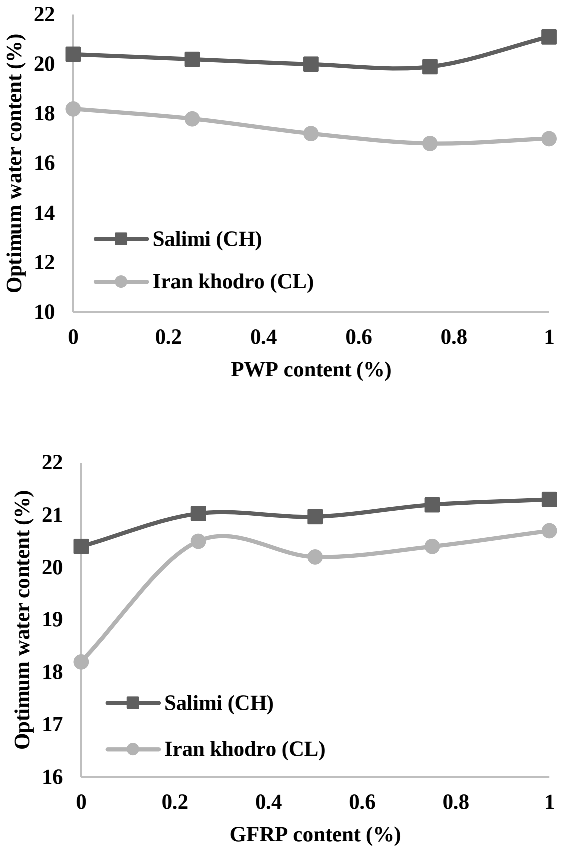


Figure 5. Effects of the mixed materials on the w_{opt}: (a) PWP content; (b) GFRP content.

These conditions can be explained according to the e_{min} (Figure 6a-b). As shown, the e_{min} was more in CH than CL in the absence of the PWP and GFRP in the specimens. Based on the above-mentioned discussions, the sodium chloride and salt particle make a new structure between the clayey particles. According to Figure 6a, increasing the PWP in the clayey soils up to 0.75% caused the e_{min} parameter to reach the minimum value. Further, the amount of decrease in CH and CL specimens were about 4.1 and 2.38%, respectively. In addition, the random mixing of the GFRP 0.5% resulted in a decline in the e_{min}. The rate of reduction in CH and CL soils were 5.1 and 5.95%, respectively. The comparison of the diagrams demonstrated that the GFRP was slightly more effective than the PWP in reducing the void ratio while increasing the γ_{dmax}. Thus, the GFRP is suitable for preventing the settlement and more deformation subgrade layer due to vehicels loading in the pavement compared to the PWP in the clayey soils.

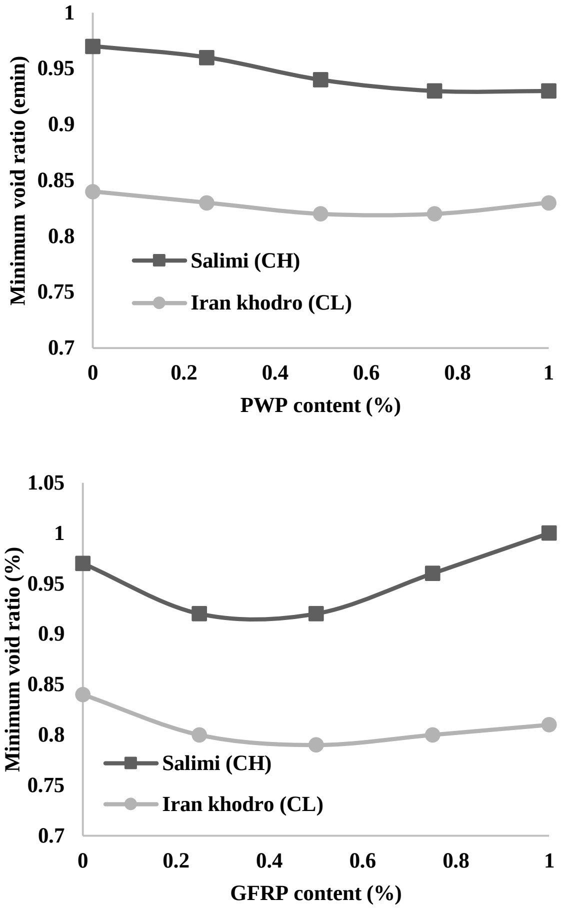
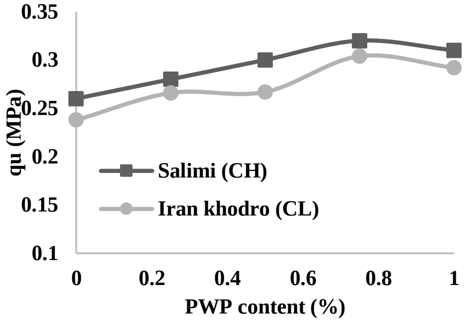


Figure 6. Effects of the mixed materials on the minimum void ratio (e_{min}) in specimens: (a) PWP content; (b) GFRP content.

3.2 Results of Uniaxial Compressive Strength Test

Uniaxial compressive strength test was conducted to investigate the effects of the PWP and GFRP on the bearing capacity and the ductility of the clayey specimens. The compressive values of the specimens at the failure moment are shown in Figure 7a-b. In an unimproved state, the uniaxial strength in the CH sample was more than that of the CL sample. Based on the diagram, the compressive strength in the CH sample was more than that of the CL sample in the case where GFRP and PWP were not added to the soils. Based on the data in Figure 7a, the uniaxial compressive strength in CH and CL samples increased when the PWP content reached 0.75%. This increase was 27% and 23% times higher than the non-improved state in the clayey soils, respectively. In addition, the uniaxial strength increased by 3.84% and 9.58% when the GFPR (0.5%) was added to the clayey soils, respectively (Figure 7b). This increase was higher in CH and CL samples as compared to pure conditions. These procedures are similar to those of Sahebkaram and Dabiri [Sahebkaram and Dabiri 2017]. Therefore, it can be explained that GFRP prevents the occurrence of shear deformation due to loading, when mixed with the clayey soil for making the subgrade layer in the pavement.



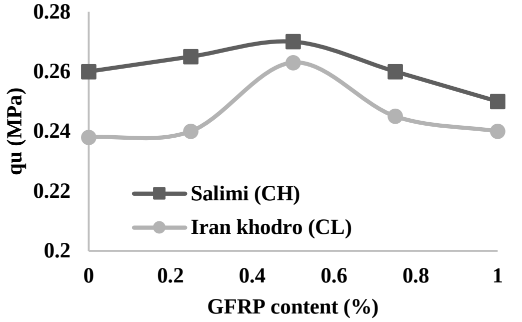
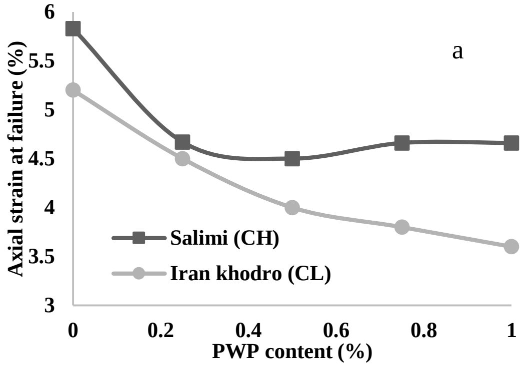


Figure 7. Effects of the mixed materials on uniaxial compressive strength in specimens: (a) PWP content; (b) GFRP content.

According to Figure 8, the axial strength rate at the failure moment in the clayey samples with no PWP or GFRP reduced by decreasing the plasticity index (PI). As illustrated in Figure 8a, the axial strain rate at the failure decreased when PWP was added to the clayey samples. However, the ductility in the specimens decreased by mixing the GFRP (0.25% content) with the samples (Figure 8b). Then, the GFRP content rose up to 0.50% and the axial strain rate increased in CH and CL samples by 2.91% and 3.84% times higher, respectively, which conforms with the results of Asadollahi and Dabiri [Asadollahi and Dabiri 2017] researches.



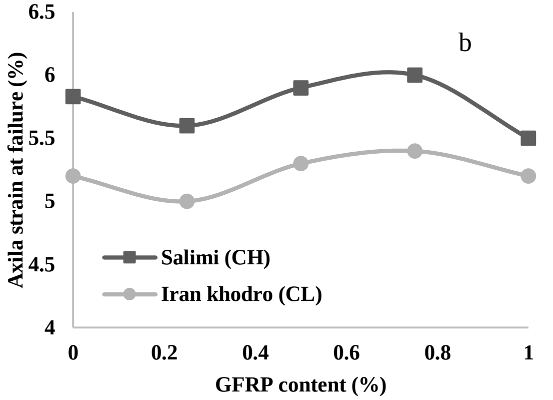


Figure 8. Effects of mixed materials on axial strength at failure in specimens: (a) PWP content; (b) GFRP content.

As displayed in Figure 9a-b, an increase in the PI in the clay resulted in an elastic modulus in an unimproved state. Meanwhile, 0.75% of the samples produced the maximum elastic modulus when GFRP and PWP were added to the samples. This increase in CH and CL samples using PWP was 9.2 and 5.26% times higher than the unimproved condition. Moreover, an increase of 4.6% and 3.04% times higher than the unimproved condition was observed by adding the GFRP to the samples. However, the comparison of the diagrams (Figure 9a-b) indicated that the PWP in the specimens was more effective than GFRP in the elastic modulus. In general, adding the PWP and GFRP (up to 0.75%) to the clayey soils led to an increase in the elastic modulus and thus reduced extensive settlement in the subgrade layer. These findings also corroborate with those of Asadollahi and Dabiri [Asadollahi and Dabiri 2017].

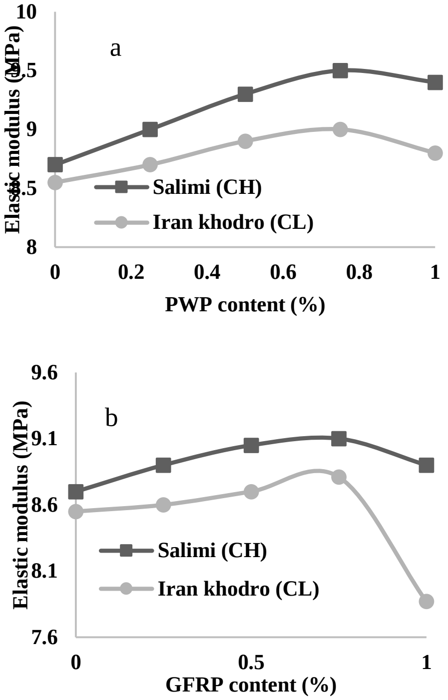


Figure 9. Effects of mixed materials on elastic modulus in specimens: (a) PWP content; (b) GFRP content.

3.3 Results of Direct Shear Test

To investigate the effect of PWP and GFRP on the bearing capacity and shear strength of the studied samples, the direct shear test was conducted under different vertical stresses (i.e., 100, 200, and 300 kPa). The variation of the cohesion in the samples are presented in Figure 10a-b. Generally, the cohesion in the CH was more than CL in an unimproved state. Based on Figure 10a, it can be claimed that increasing the PWP in the specimens resulted in a gradual decline in the cohesion in the improved soils. According to Figure 10b, the cohesion in the specimens increased when the GFRP content reached 0.5%. This increase was observed by 15.3% in both clayey soils on average. This is in line with the result obtained by Asadollahi and Dabiri [Asadollahi and Dabiri 2017].

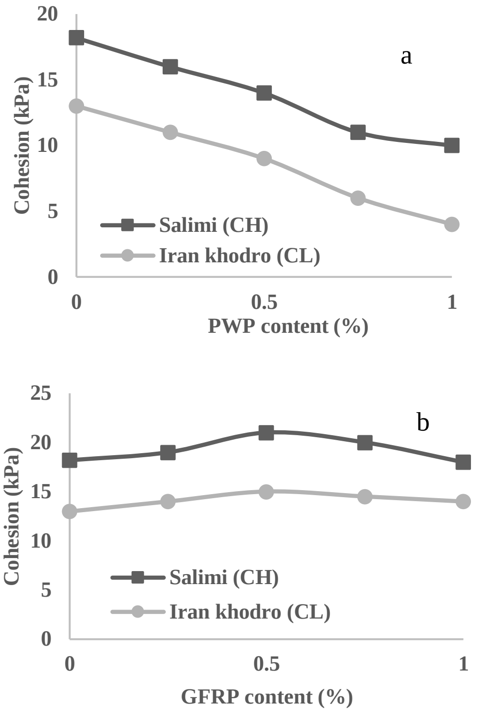


Figure 10. Effects of the mixed materials on cohesion in specimens: (a) PWP content; (b) GFRP content.

Furthermore, the variation of the integral friction angle (φº) soil samples can be observed in Figure 11-a-b. In an unimproved state, the internal friction angle of the CL was more than that of the CH. Moreover, the internal friction angle in the clayey soils (i.e., CH and CL) increased by 18.9 and 18.7%, respectively, when the PWP (0.75%) was added to the samples (Figure 11a). Additionally, the internal friction angle rate in the CH and CL increased by 24.3 and 28.2% in the clayey samples containing the GFRP (0.5%), respectively. However, comparing the diagrams (Figure 11a-b), the results revealed that the effectiveness of GFRP in the specimens was more obvious than the PWP regarding the internal friction angle.

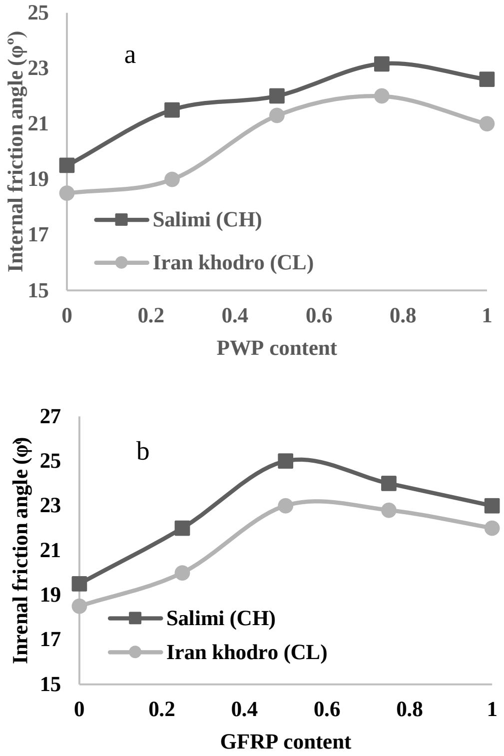
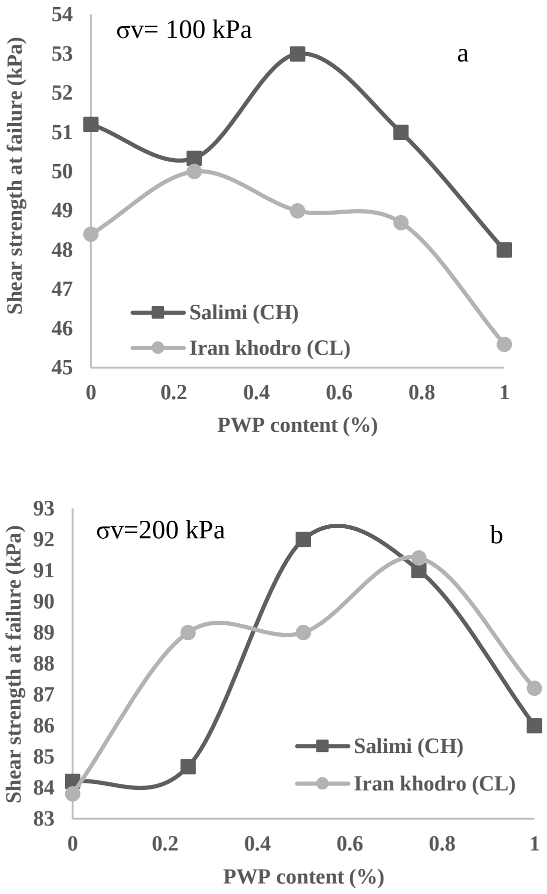


Figure 11. Effects of mixed materials on internal friction angle in specimens: (a) PWP content; (b) GFRP content.

Figures 12 and 13 (series of a-b-c) depict the variations of the shear strength at the failure in the improved samples under various vertical stresses (i.e., 100, 200, and 300 kPa). Based on the findings, 0.5% content PWP in CH specimens could increase the bearing capacity in low and medium vertical stresses. Moreover, the shear strength increased in a high vertical stress value when GFRP content reached 0.75%. Contrarily, that the shear strength in the improved specimens increased in the CL sample when GFRP and PWP content reached to 0.5% (Figure 13a-b-c). However, PWP and GFRP affected the bearing capacity in low and medium vertical stresses and the high value of loading, respectively. As shown in Tables 4 and 5, the effects of PWP and GFRP on the shear strength was found to be a quantitatively effective rate at the failure moment of the studied samples. According to the obtained results, the PWP and GFRP of 0.5% in the improved clayey soils had the highest effect on increasing the rate of the shear strength in all vertical stresses. These findings are in conformity with the results obtained by Asadollahi and Dabiri [Asadollahi and Dabiri 2017], as well as Sahebkaram and Dabiri [Sahebkaram and Dabiri 2017].



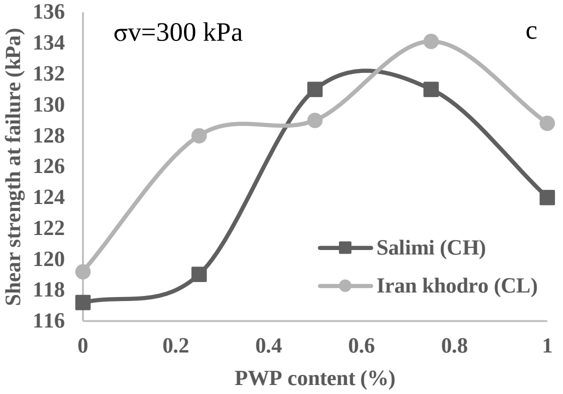
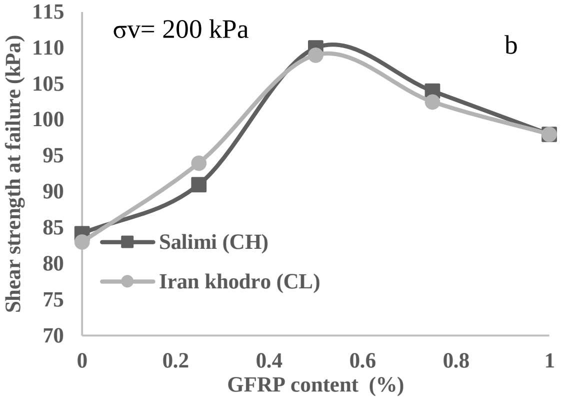
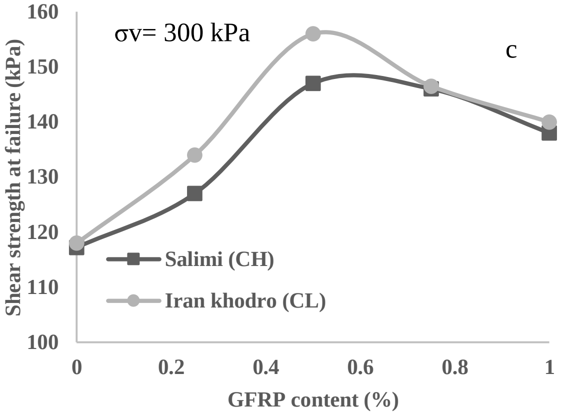


Figure 12. Effects of PWP content on shear strength at failure in specimens: (a) σv=100 kPa; (b) σv=200 kPa; (c) σv= 300 kPa





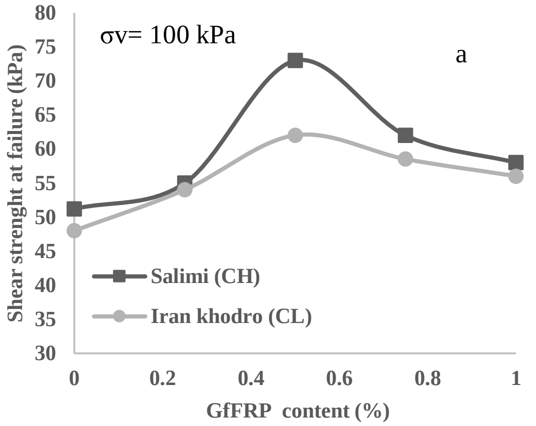


Figure 13. Effects of GFRP content on shear strength at failure in specimens: (a) σv=100 kPa; (b) σv=200 kPa; (c) σv= 300 kPa

Table 4. Effects of PWP and GFRP content on the Variations of the Shear Strength at Failure in Improved CH Specimens

Stress	σv=100 kPa		σv=200 kPa		σv=300 kPa	
Particle Percent	PWP content	GFRP content	PWP content	GFRP content	PWP content	GFRP content
0.25	-1.67%	7.42%	0.57%	8.07%	1.55%	8.36%
0.5	5.28%	32.7%	8.64%	20.87%	10.06%	15.74%
0.75	-3.77%	-15.06%	-1.08%	-5.45%	0.5%	-0.68%
1	-5.88%	-6.45%	-5.49%	-5.76%	-5.34%	-5.47%

Note. PWP: Polypropylene waste plastic; GFRP: Glass fiber reinforced polymer.

Table 5. Effects of PWP and GFRP content on the Variations of Shear Strength at Failure in Improved CL Specimens

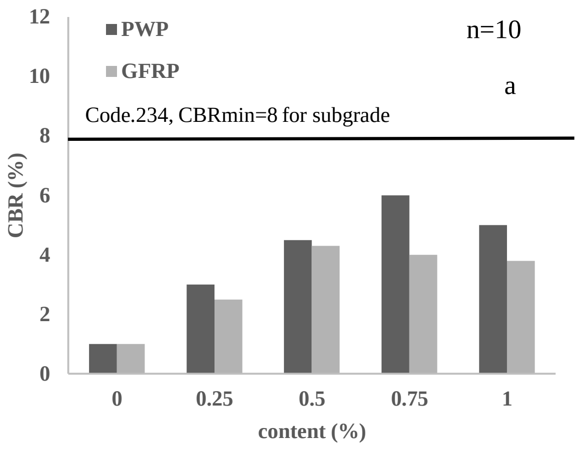
Stress	σv=100 kPa		σv=200 kPa		σv=300 kPa	
Particle Percent	**PWP content**	**GFRP content**	**PWP content**	**GFRP content**	**PWP content**	**GFRP content**
0.25	2%	12.5%	0.2%	13.25%	0.78%	13.55%
0.50	3.3%	14.81%	6.2%	15.95%	7.38%	16.41%
0.75	-0.61%	-5.64%	2.69%	-5.96%	-2.95%	-6.08%
1	-6.36%	-4.27%	-4.59%	-4.39%	-3.95%	-4.43%

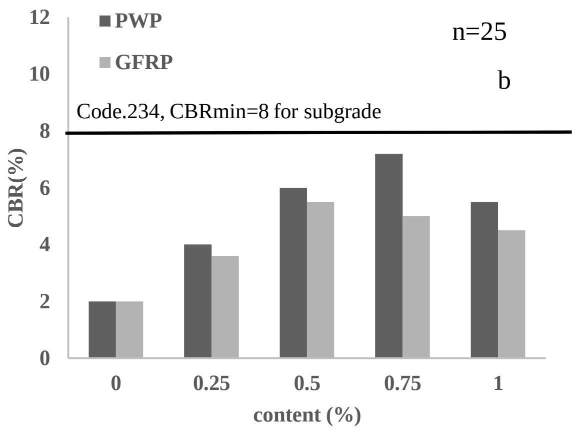
3.4 Results of CBR Test

As mentioned earlier, the current study mainly sought to evaluate the effects of GFRP and PWP particles on geotechnical properties and the bearing capacity of the clayey soil with different plasticity indexes for using the subgrade layer design in the pavement. Therefore, the CBR test was performed on improved and unimproved clayey specimens (i.e., CH and CL) in dry and saturated conditions using three compaction energies (i.e., 10, 25, and 56 blow counts). The CBR values were estimated per specimen in 25 and 50 mm piston penetrations. The estimated results were compared with Code.234 criteria. The obtained results can be explained in two parts as follows:

3.4.1 Dry Condition

As shown in Figure 14a-b-c, adding PWP and GFRP in specimens resulted in an increase in the bearing capacity of the CH specimens. The CBR value showed that, according to the Iranian code.234, the improved specimens were suitable for the subgrade layer construction when PWP and GFRP amounts reached 0.5% and 0.75% in the CH samples in 25 mm penetration and high energy compaction, respectively. Moreover, similar to the previous part, PWP and GFRP were useful for increasing the bearing capacity in 50 mm piston penetration (Figure 15a-b-c). With a difference that in medium and high compaction energy based on Code.234, by mixing 0.25 to 1% content PWP and GFRP in the CH soil, improved soil prepared for make subgrade layer. Nevertheless, the PWP was more effective than GFRP in both conditions.





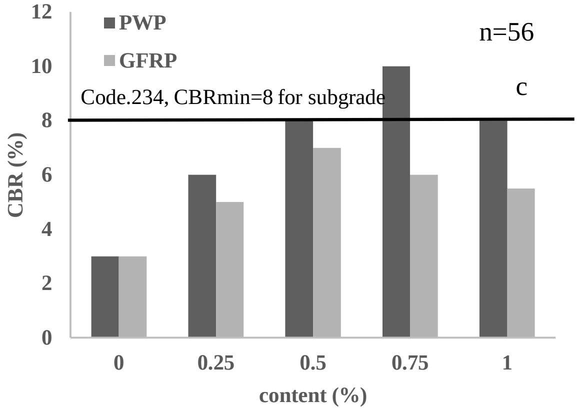
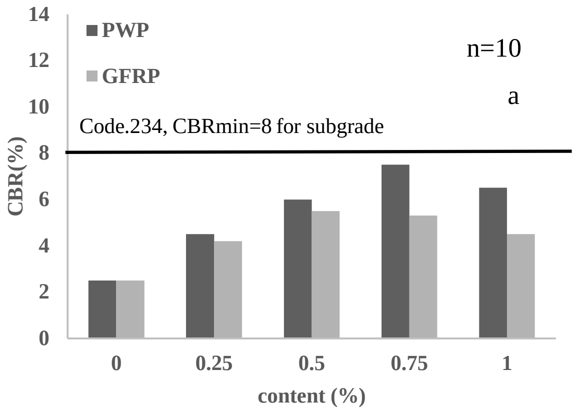
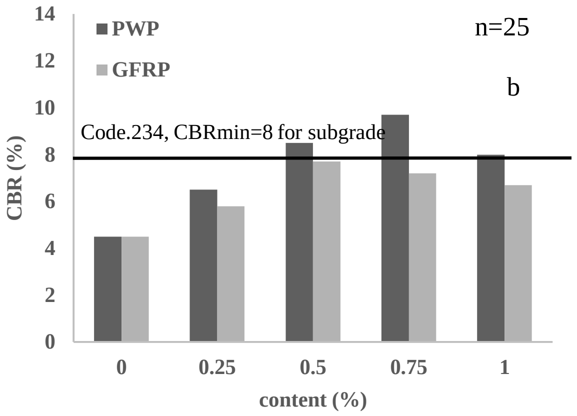


Figure 14. Effects of PWP and GFRP content on CBR values in CH specimens for 25 mm penetration piston in several compaction energies





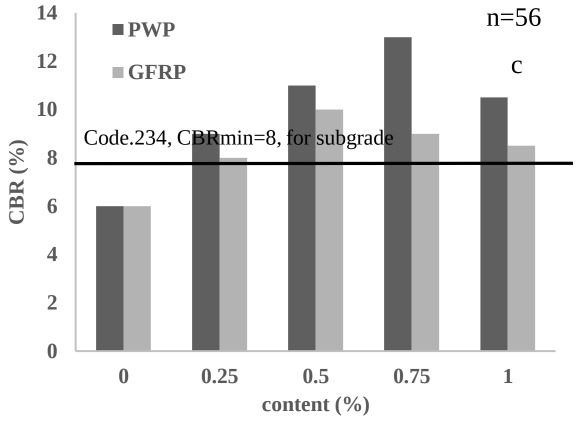


Figure 15. Effects of PWP and GFRP content on CBR values in CH specimens for 50 mm penetration piston in several compaction energies: (a) n=10; (b) n=25; (c) n=56

Based on Figure 16a-b-c, similar to the CL soil, the bearing capacity and strength increased more than the unimproved condition by mixing PWP and GFRP in the CL samples. Nonetheless, the findings indicated that increasing the GFRP up to 0.5% enhanced the value of the CBR at the medium compaction energy. Based on Code.234, the reinforced specimen is appropriate for constructing the subgrade layer. Furthermore, it was observed that the CBR amounts in the reclaimed specimens increased by adding the GFRP content (0.5 and 1%) in high compaction energy. However, the GFRP (0.5%) was more effective than the other contents. In addition, the obtained results represented that PWP was less effective than GFRP in CL specimens.

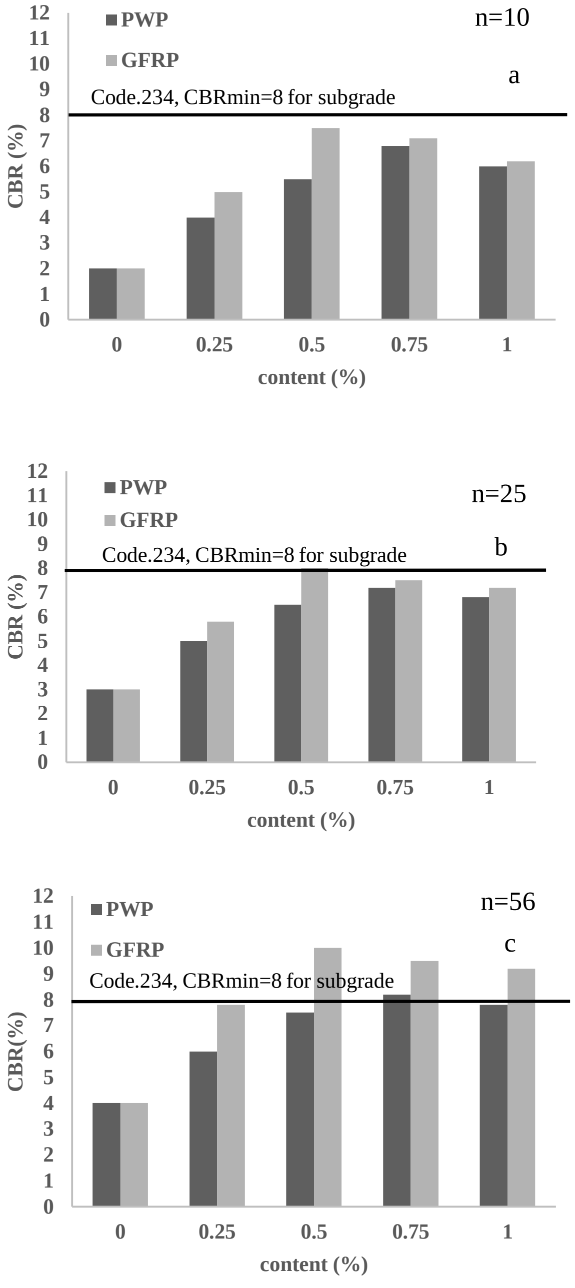
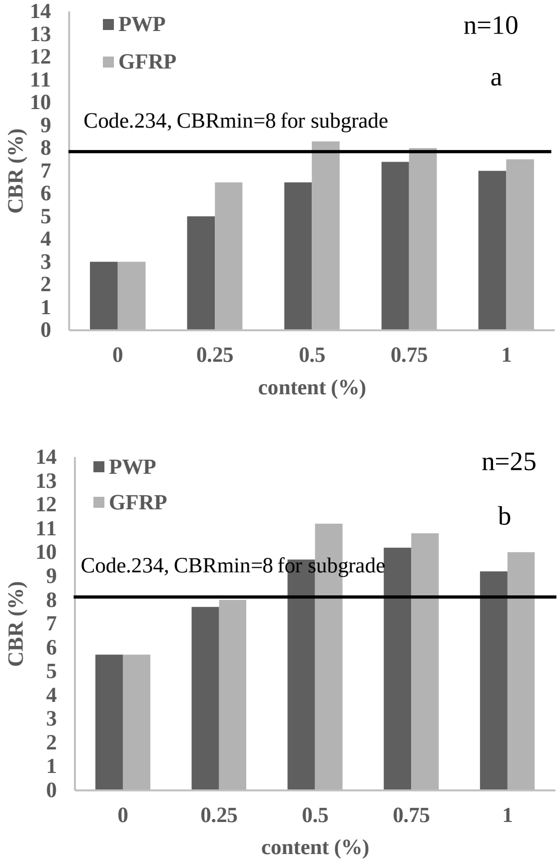


Figure 16. Effects of PWP and GFRP content on CBR values in CL specimens for 25 mm penetration piston in several compaction energies: (a) n=10; (b) n=25; (c) n=56

The CBR values in 50 mm piston penetration in the specimens (Figure 17a-b-c) showed that increasing the compaction energy led to an increase in PWP and GFRP content in order to reinforce the specimens. In other words, GFRP (0.5%) and PWP (0.75%) had the highest level of efficiency in medium and high energy compactions regarding increasing the CBR for improving the CL specimen so that to build the subgrade layer based on Code. 234.



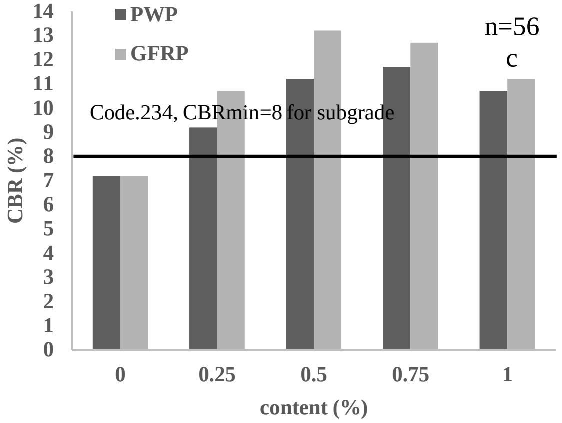


Figure 17. Effects of PWP and GFRP content on CBR values in CL specimens for 50 mm penetration piston in several compaction energies: (a) n=10; (b) n=25; (c) n=56

3.4.2 Saturation Condition

Similar to a dry condition, CBR tests were performed on improved and unreinforced specimens in a saturated condition for 25 and 50 mm piston penetrations. As can be observed in Figure 18a-b-c, the bearing capacity and CBR values reached the maximum levels by increasing the contents of PWP and GFRP up to 0.75% in CH specimens (in 25 mm penetration piston). However, the CBR value became acceptable based on Code.234 for the construction of the subgrade layer in high energy compaction according to Figure 20c when PWP (0.75%) was mixed with the CH specimen. Similarly, based on the obtained results in Figure 19a-b-c, the CBR equivalent of PWP (0.75%) content in CH specimens was useful for improving the soil specimens when the piston was penetrated 50 mm in the specimens in the medium compaction energy. In high energy compaction, CBR values increased by using the PWP (0.25 to 1%) and mixing GFRP (0.5 to 0.75%) with the specimens. According to these conditions and Code.234, the improved CH sample was suitable for subgrade layer construction. Nevertheless, the PWP was more effective than GFRP in both penetration values.

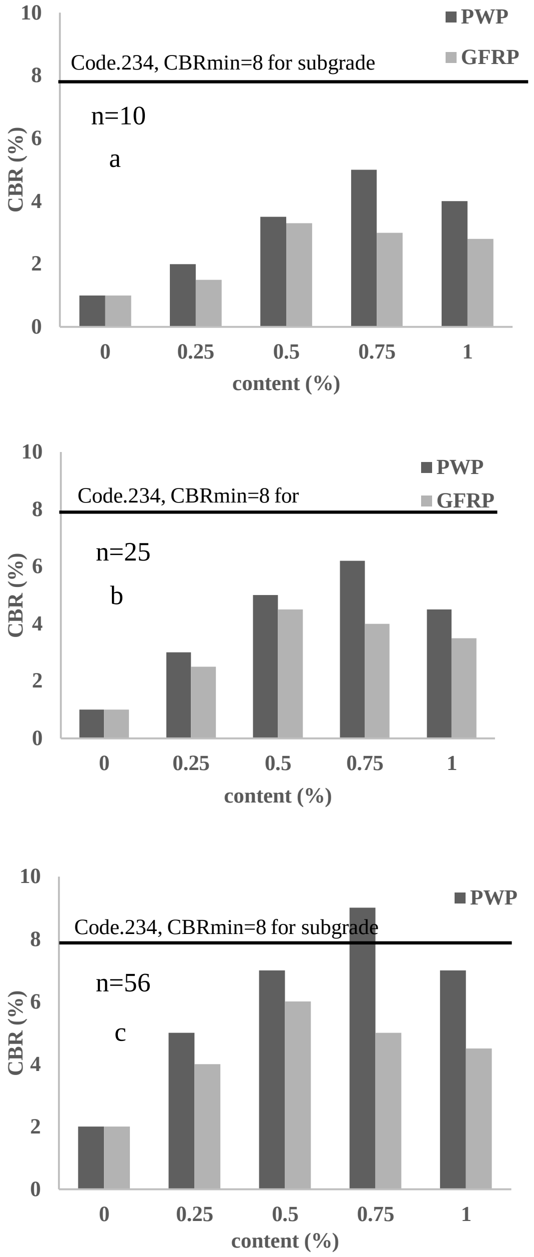


Figure 18. Effects of PWP and GFRP content on CBR values in CH specimens for 25 mm penetration piston in several compaction energies: (a) n=10; (b) n=25; (c) n=56

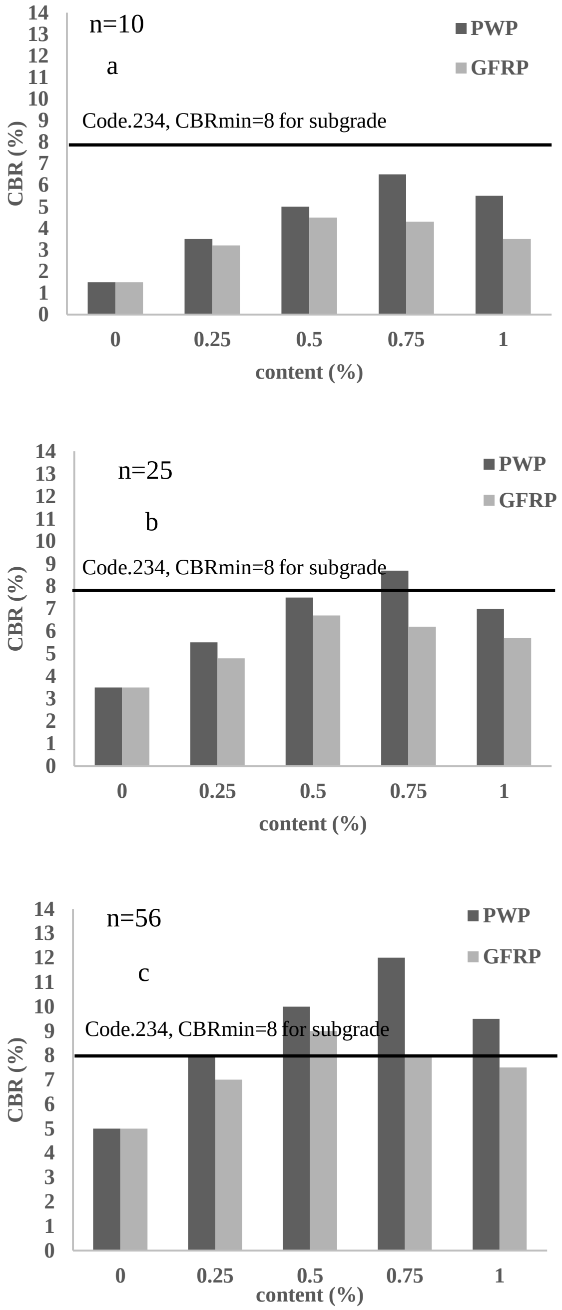
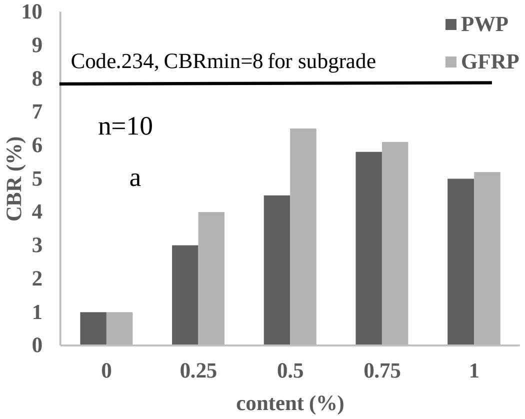


Figure 19. Effects of PWP and GFRP content on CBR values in CH specimens for 50 mm penetration piston in several compaction energies: (a) n=10; (b) n=25; (c) n=56

Likewise, the bearing capacity and strength enhanced and were more than the unimproved condition by increasing the PWP and GFRP up to 0.75% in the CL and CH samples (Figure 20a-b-c). However, the the findings demonstrated that the CBR value increased in high compaction energy when GFRP reached 0.5%. Based on Code.234, the reinforced specimen was appropriate for the subgrade layer as well. Nonetheless, an increase in the GFRP (from 0.5 to 1%) led to a decrease in the CBR value. Further, the results related to the 25 mm piston penetration showed that the GFRP was more effective than PWP in CL specimens. Similarity, the CBR equivalent to PWP (0.75%) and GFRP (0.5%) content in CL specimens was appropriate for the improved subgrade in medium and high compaction energies when the piston was penetrated 50 mm in the specimens (Figure 21a-b-c). In other words, according to Code.234, CL specimens were prepared for making the subgrade layer by adding the PWP (0.75%) and GFRP (0.5%).



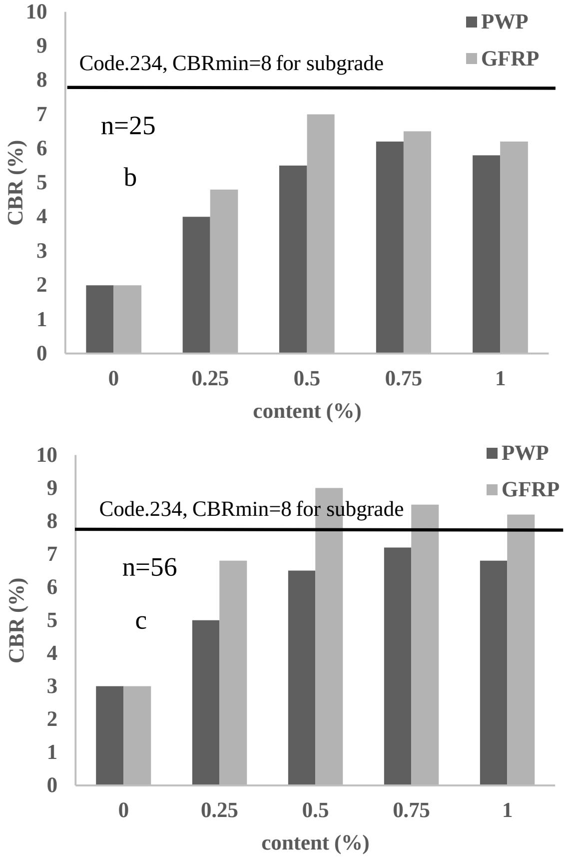
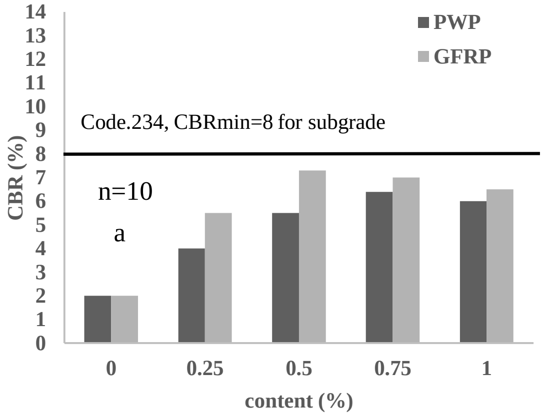


Figure 20. Effects of PWP and GFRP content on CBR values in CL specimens for 25 mm penetration piston in several compaction energies: (a) n=10; (b) n=25; (c) n=56



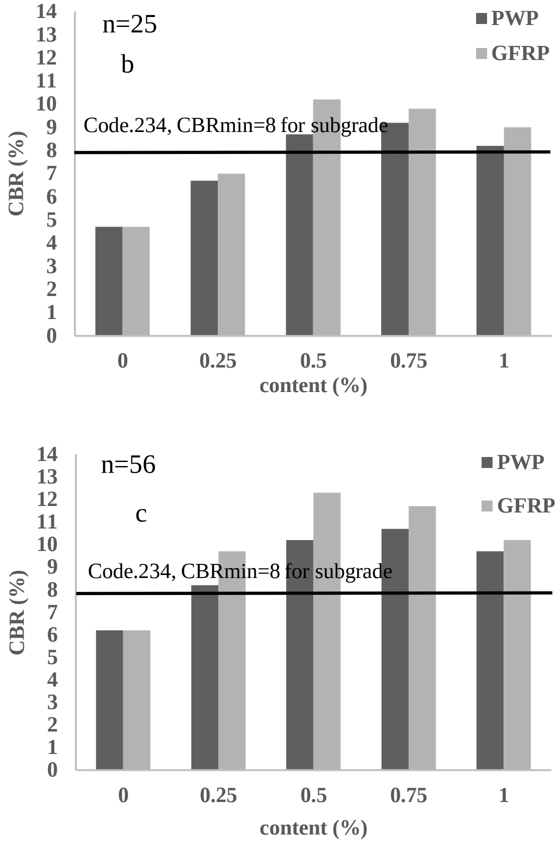


Figure 21. Effects of PWP and GFRP content on CBR values in CL specimens for 50 mm penetration piston in several compaction energies: (a) n=10; (b) n=25; (c) n=56

Tables 6 and 7 present the rate of PWP and GFRP influence on the CBR values of the improved specimens in both dry and saturated conditions. Based on the results, the CBR values in CH and CL specimens increased for PWP (2.37% and 1.435% on average, respectively) and GFRP (1.485% and 1.575% on average, respectively) when PWP (0.75%) and GFRP (0.5%) were added to the studied samples in a dry condition as compared with the unimproved samples. Further, similar conditions were observed in a saturated condition so that mixing the same amount of PWP and GFRP in CH and CL specimens, CBR values increased for PWP (3.13 and 2.025% on average, respectively) and GFRP (1.91 and 2.46% on average, respectively) as compared to the specimens with the added materials. The findings further revealed that the PWP and GFRP were effective in increasing the bearing capacity of CH and CL specimens, respectively. Furthermore, the PWP and GFRP were more impressive in specimens with a saturated condition as compared to a dry condition. Moreover, the high compaction energy (n=56 blow count) with 50 mm piston penetration was considered regarding the pavement design.

Table 6. Effects of PWP and GFRP content on the Variations of CBR Values in Improved Specimens (A Dry Condition).

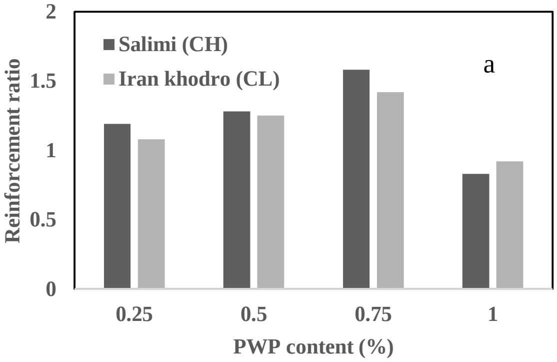
PWP								
Percent	**0.25**		**0.5**		**0.75**		**1**	
Test	**CBR**		**CBR**		**CBR**		**CBR**	
Soil type	(25 mm)	(50 mm)	(25 mm)	(50 mm)	(25 mm)	(50 mm)	(25 mm)	(50 mm)
CH	1.3%	0.58%	2.39%	1.04%	3.3%	1.44%	2.47%	1.04%
CL	0.72%	0.95%	1.26%	0.69%	1.61%	1.26%	1.4%	0.8%
GFRP								
Percent	**0.25**		**0.5**		**0.75**		**1**	
Test	**CBR**		**CBR**		**CBR**		**CBR**	
Soil type	(25 mm)	(50 mm)	(25 mm)	(50 mm)	(25 mm)	(50 mm)	(25 mm)	(50 mm)
CH	0.99%	0.43%	2.11%	0.86%	1.83%	0.74%	1.62%	0.56%
CL	1.13%	0.68%	1.97%	1.18%	1.8%	1.1%	1.6%	0.91%

Table 7. Effects of PWP and GFRP content on the Variations of CBR Values in Improved specimens (A Saturated Condition).

PWP								
Percent	**0.25**		**0.5**		**0.75**		**1**	
Test	**CBR**		**CBR**		**CBR**		**CBR**	
Soil type	(25 mm)	(50 mm)	(25 mm)	(50 mm)	(25 mm)	(50 mm)	(25 mm)	(50 mm)
CH	1.5%	0.83%	3%	1.49%	4.2%	2.06%	3%	1.52%
CL	1.22%	0.58%	2.13%	1.08%	2.76%	1.29%	2.38%	1.1%
GFRP								
Percent	**0.25**		**0.5**		**0.75**		**1**	
Test	**CBR**		**CBR**		**CBR**		**CBR**	
Soil type	(25 mm)	(50 mm)	(25 mm)	(50 mm)	(25 mm)	(50 mm)	(25 mm)	(50 mm)
CH	1%	0.63%	2.6%	1.23%	2.16%	1.07%	1.85%	0.81%
CL	1.88%	0.93%	3.33%	1.6%	3.06%	1.48%	2.67%	1.26%

In addition, the influences of the PWP and GFRP on improved specimens were evaluated according to the reinforcement ratio (i.e., equation No.1). The results are displayed in Figures 22 and 23. Based on the findings, in a dry condition, the reinforcement ratio was equal to 1.58 when mixing the PWP (0.75%) content with CH specimens, which is similar to the above-mentioned reasons. Moreover, this ratio was about 1.68 in CL samples that were improved by the GFRP (0.5%). Additionally, the reinforcement ratio in CH and CL specimens with equivalent PWP and GFRP content in a saturated condition, as in dry conditions, were equal to 1.83 and 1.93, respectively. These results confirmed that the reinforcement materials in a saturated condition were more effective compared to a dry condition. The following equation was used in this regard:

$$\text{Reinforcement ratio}=\frac{CBR\ (with\ reinforcement)}{CBR\ (\text{without reinforcement})} \qquad (1)$$



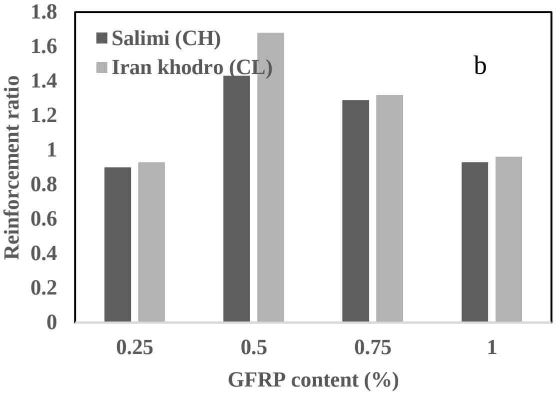


Figure 22. Effects of the mixed material on reinforcement ratio in the specimens (a dry condition): (a) PWP content, (b) GFRP content

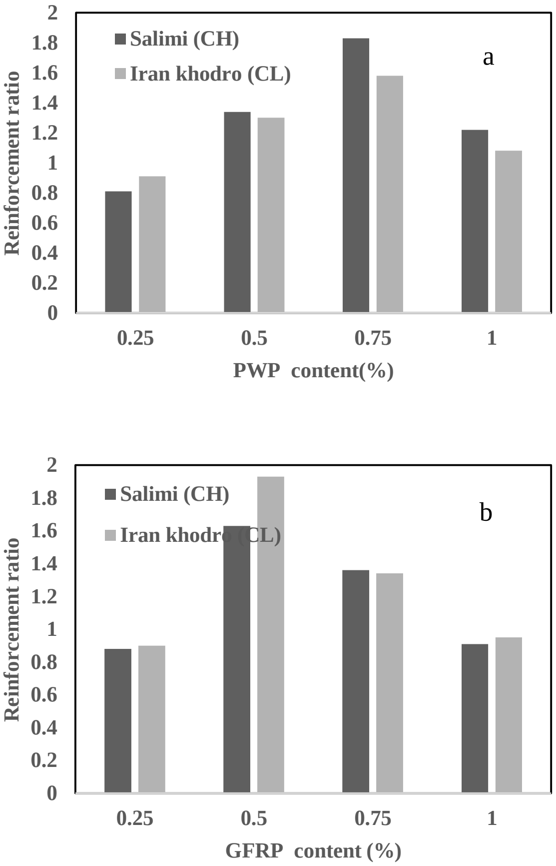
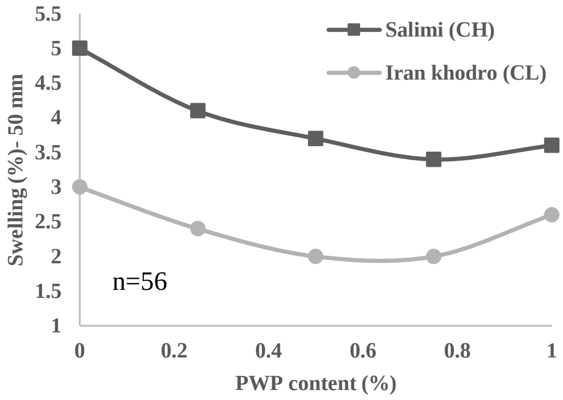


Figure 23. Effects of the mixed material on reinforcement ratio in the specimens (a saturated condition): (a) PWP content, (b) GFRP content.

The results from the CBR test in the present study were compared with those of several other studies [e.g., Dean and Fretting, 1986; Sadeghi and Dabiri, 2015; Ghasemvash and Dabiri, 2019]. Based on this comparison, the GFRP and PWP were more effective than the geotextile for improving geotechnical properties and the bearing capacity in the clayey soil in dry conditions.

3.4.3 Swelling

Furthermore, the effects of the PWP and GFRP on the swelling potential of the specimens were explored according to the CBR test in a saturated condition. The results are shown in Figure 24a-b. The findings indicated that CH samples had a high swelling potential in an unimproved condition as compared to CL specimens. The swelling potential decreased by 32% and 33% in both CH and CL samples, When PWP increased to 0.75% in the specimens, respectively. As shown in Figure 24b, the swelling potential reduced by 60% when GFRP (0.75%) was added to the specimens. However, PWP (0.5%) could reduce the swelling in CH samples by 20%.



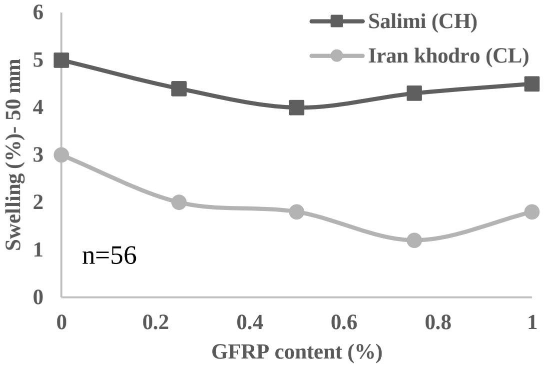


Figure 24. Effects of the mixed material on the swelling potential of the specimens: (a) PWP content, (b) GFRP content.

3.5 Results of Permeability Test

Permeability was one of the important factors of the applied materials in the pavement design. The present research investigated the effects of PWP and GFRP on CH and CL specimens. In an unimproved condition, CL specimens had a high permeability as compared to CH samples. As displayed in Figure 25a-b, permeability enhanced in both CH and CL specimens when PWP content increased in the specimens. Contrarily, permeability decreased in CH and CL samples by 10 and 11% when GFRP (0.25%) was added to the specimens, respectively. In addition, an increase in PWP and GFRP resulted in an increase of 1% in permeability. These results were confirmed by Asadollahi and Dabiri [Asadollahi and Dabiri 2017] as well.

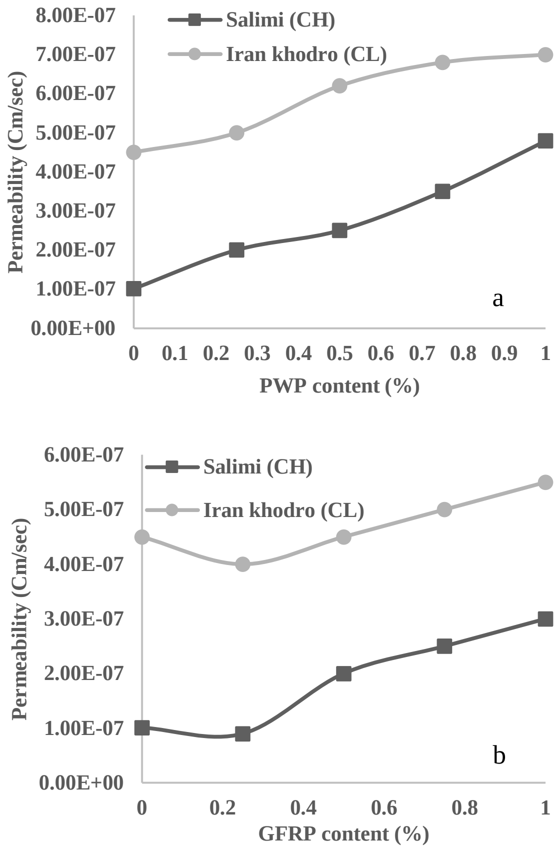


Figure 25. Effects of the mixed material on the permeability of the specimens: (a) PWP content, (b) GFRP content.

4. Conclusion

Pavement design is considered as one of the important issues of safety performance in traffic and transportation. The subgrade layer as a foundation in the pavement body can be a compacted embankment, a natural ground surface, or an improved backfill considering that the final subgrade layer should withstand the loading since the vehicle crosses over the pavement layers. This study compared the effects of PWP and GFRP in the clayey soil with different plasticity indexes in making the subgrade layer. The important findings of the present study could be summarized as follows:

1. Based on the findings, the cohesion enhanced in the specimens when the GFRP content reached 0.5%. This increase in both clayey soils was about 15.3% on average. On the other hand, PWP had a negative effect on the cohesion of the specimens. It means that an increase in the PWP content of the clayey soils led to a decline in the cohesion of the specimens. The results further revealed that the internal friction angle (φ^o) generally increased in both CH and CL specimens by 18.9 and 28.2% by adding PWP (0.75%) and GFRP (0.5%) to the sample, respectively. Therefore, the effectiveness of GFRP on the specimens was more than PWP in the internal friction angle. Furthermore, 0.5 % of the PWP and GFRP in the improved clayey soils can be most effective in increasing the rate of the shear strength in all vertical stresses.

2. In dry and saturated conditions, the CBR test values showed that PWP (0.75%) in the CH specimens had the highest effect on increasing the bearing capacity in preparing the improved soil for the subgrade layer according to Code.234 whereas GFRP (0.5%) in CL specimens had the best role in the improvement. However, PWP and GFRP were more remarkable in the specimens with a saturated condition as compared to a dry one.

3. The PWP and GFRP materials were effective in the swelling potential of the clayey soil. In other words, the swelling

potential decreased by about 32% and 33% in both CH and CL samples when the PWP content increased up to 0.75% in the specimens, respectively. In addition, this potential decreased by 60% when the GFRP (0.75%) was added to the specimens. However, PWP (0.5%) could reduce the swelling in CH samples by 20%.

According to the obtained results, the clayey soils in the areas under investigation were alkaline and limy. Therefore, based on the chemical reaction between lime-clay particles and fine cemented formation made a new structure with bigger particles. This condition in the CH led to the appearance of a new structure between the clay particles while PWP (0.75%) mixed with new particles caused the void in inter fine particles reach the minimum values. As a result, compressibility, bearing capacity, and permeability increased in the improved CH specimen while swelling represented a decrease. Moreover, based on Code. 234, the reinforced clayey soil was prepared to make the subgrade layer.

However, the presence of minor salt and sodium chloride, as well as an acidic condition in the CL specimen, on the one hand, and the existence of the quartz with silica particles between the clay fine grains, on the other hand, led to a condition in which PWP in the improved soil failed to show the proper behavior. In contrast, the presence of 0.5% GFRP in the CL specimen led to a relative increase in compressibility, strength, and permeability while the swelling indicated a decline. In conclusion, considering the type of clayey soil, both added materials can be used to prepare the subgrade layer. The comparison results from the CBR test and previous studies [e.g., Dean and Fretting, 1986; Sadeghi and Dabiri, 2015; Ghasemvash and Dabiri, 2019] demonstrated that GFRP and PWP are more effective than the geotextile for improving geotechnical properties and bearing capacity in the clayey soil for using the subgrade layer in dry conditions. Therefore, future studies are suggested to evaluate the effects of the percent content of the material, locating, the length of the reinforced fiber polymer and other waste materials for soil improvement in the foundation, retaining wall, pavement, and other constructions.

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