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Review Article:

An Experimental Study on Stabilization of Expansive Soil Using Steel Slag and Crushed Limestone

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Abstract

This study is carried out to evaluate the effect of steel slag (SS) as a by-product and crushed limestone (CRL) as additives on the geotechnical properties of expansive soil. A series of laboratory tests were conducted on natural and stabilized soils. Both of SS and CRL were added by 0, 2.5, 5, 10, 15, and 20% to the soil. The conducted tests are consistency limits, specific gravity, hydrometer analysis, modified Proctor compaction, swelling pressure, swelling percent, and California Bearing Ratio (Soaked CBR). The results showed that the values of liquid limit, plasticity index, optimum moisture content, were decreased. Also, with the addition of the mixture of "10% SS with 10% CRL" which cured for 28 days, the values of swelling pressure and swelling percent were reduced by 69.8% and 84.3% respectively. Whereas, the values of maximum dry density (MDD) increased from 17.66 kN/m3 to 18.79 kN/m3 and from 17.66 kN/m3 to 18.25 kN/m3 with the addition of 20%SS and 15% CRL respectively. Also, with the addition of the mixture of 10% SS+10% CRL and 20% SS+15% CRL individually, the values of CBR increased from 3.4% to 26.7% and from 3.4% to 39.5% respectively. The steel slag and crushed limestone were found to be successfully improving the geotechnical properties of expansive soil.

1. Introduction

Expansive soils are problematic in nature due to the existence of montmorillonite clay mineral. It has a high tendency to volume change upon a change in moisture content that known as swelling potential. This swelling exerts a leading force which seriously affects building foundations, basement floors, sidewalks, pipelines, and so forth. The indirect consequence of the swelling has coasted enormous damages, including repair and rehabilitation of many foundations (Nelson and Miller, 1992). Several techniques have been utilized to improve the properties of expansive soils, such as, dewatering, earth reinforcement, and soil stabilization.

Soil stabilization is one of the solutions for improvement of expansive soils by alteration of soil properties to meet specific engineering requirements.

It may consist of either increasing the density of soil by controlled compaction or by adding additives to increase the apparent cohesion and/or frictional resistance (Hossain and Khandaker, 2011).

Some researchers used crushed limestone (CRL) for improving the properties of expansive soils (Al-Khashab and Thafer, 2008). Other researchers have employed steel slag (SS) waste material of steel factories for many purposes such as (Chen et al., 2007), mortar road base material (Shen et al., 2009), cement manufacturing (Huang and Lin, 2010), heavy metals immobilization (Grubb et al., 2011), and soil improvement (Liang et al., 2013; James et al., 2018). This study is an attempt to improve the geotechnical engineering properties of expansive soils using the by-product of steel slag and crushed limestone with various percentages.

2. Studies Related to Expansive Soil Stabilization Using Additives.

Patil et al. (2011) had studied the swell behavior of expansive soil by using independently silica sand and granular tire rubber as additives. Their results showed that with an increase in additive materials and increase in surcharge stress, the swell reduction increases. With better swell reduction in case of using stiff sand than flexible tire rubber material.

James and Pandian (2013) investigated the effect of eggshell powder on the geotechnical properties of expansive soil. The experimental program involved determination of index properties, strength, and swell of the modified soil. It was found that addition of eggshell powder to soil resulted in a reduction in plasticity characteristics, improvement in the strength of the soil, and contraction in swelling of the soil.

Krishnan et al. (2014) had studied the combined effect of class C fly ash and phosphogypsum on unconfined compressive strength (UCS) of expansive soil and had found that UCS increases by the addition of these two stabilizers which increases further with an increase in curing period.

Rashmi et al. (2016) conducted laboratory tests on expansive soil stabilized with groundnut shell ash. Their results show that, the decrease in plasticity index and the increase in dry density improve the bearing capacity of the clayey soil.

Venkata et al. (2017) studied the effect of utilization of various percentages of waste bottle plastic strips and lime of expansive soil. They found that CBR and MDD values were increased and O.M.C was decreased by adding 5% of lime with 6% waste plastic into the expansive soil.

Goud et al., (2018) studied the expansive soil stabilization using coir pith and lime as stabilizer. The optimum content of coir pith and lime were determined based on the UCS of the treated soil and compared with that of UCS of untreated soil.

3. Materials and Experimental Methods

3.1. Materials

3.1.1. Expansive Soil

The used expansive soil in this study was collected from Qirga site in Sulaimani city locates in the north part of Iraq with Latitude 35º29'55'' and Longitude 45º27'59''. The soil is stiff clay with dark brown color. The soil sample was taken at a depth of 1.0 meter from the natural ground surface, and stored in plastic bags to keep their field moisture content. Then, the soil samples were tested in the soil laboratory of the College of Engineering at the University of Sulaimani, Iraq. The soil samples were dried, pulverized, and sieved through sieve No.4 (4.75 mm) to eliminate gravel fraction. This dried and sieved soil is stored in airtight containers ready for stabilization purpose. The geotechnical properties for the soil sample are presented in Table (1).

3.1.2. Steel Slag (SS)

Steel slag is a by-product of the steel manufacturing process. It is producing during the separation of molten steel from impurities in steel-making furnaces. For this study, steel slag was collected from Suli-Steel factory in Sulaimani city, Iraq. Steel slag samples were crushed into finer particles and passed through sieve No.40 (0.425 mm), as shown in Figure (1), then stored in a plastic bag. Steel slag mixed with soil in various percentages of 2.5, 5, 10, 15, and 20% added by the weight of dry soil samples. The specific gravity of the steel slag sample was 3.31.

3.1.3. Crushed Limestone (CRL)

In this study, the sample of crushed limestone was taken from the Tlazait crusher locates 30 km South-East of Sulaimani city, Iraq. The crushed rock was passed through sieve No. 40 (0.425 mm) and stored in a plastic bag for laboratory work, as shown in Figure (2). Then, it was mixed with soil in various percentages of 2.5, 5, 10, 15, and 20% added by the mass of dry soil samples. The specific gravity of the crushed limestone sample was 2.81.

3.2. Experimental Works

A set of laboratory tests were done according to ASTM standards. The tests were carried out on both natural and stabilized soil samples with steel slag and/or crushed limestone.

1- Atterberg limits (ASTM D 4318-10).
2- Hydrometer analysis (ASTM D422).
3- Specific gravity (ASTM D 854-14).
4- Modified Proctor Compaction (ASTM D1557-12).
5- Swelling Pressure and Swelling Percent (ASTM D 4546-08).
6- Unconfined Compressive Strength (UCS) (ASTM D2166-16).
7- California Bearing Ratio (CBR) (ASTM D1883-16).

3.3. Mix Design for Stabilization Materials

Both of SS and CRL were added individually to the expansive soil samples by the replacement method with various percentages of 0, 2.5, 5, 10, 15 and 20%. After that, the mixture of both SS and CRL were added to the expansive soil samples. The tests mentioned previously were conducted on both natural and stabilized samples with SS and CRL individually and together as a mixture.

4. Results and Discussion

4.1. Effect of SS and CRL on Atterberg limits.

The variation of Atterberg limits and linear shrinkage with added SS or CRL individually or together are shown in Figures (3) to (6). It can be seen that all those limits were decreased with the addition of SS or CRL individually or together. This may be attributed to the reduction of absorbed water % by soil. However, more decrease is obtained with the addition of SS and CRL together compared with their addition of each of them separately. The reduction in liquid limit, plastic limit, and linear shrinkage limit values were due to a decrease in the thickness of the double layer of the clay particles. That is because of the cation exchange reaction, which causes an increase in the attraction force leading to flocculation of the particles. When SS and CRL were mixed with the soils, the particle size of the mixed sample increased. Due to the increase of particle size, the surface area of particles gets decreased. Moreover, the quantities of clay mineral in soils decrease with the increase of SS and CRL content in the soil mixture. As a result, the water holding capacity of soil mixture gets decreased, and then, liquid limit, plastic limit, and linear shrinkage limit were decreased.

4.2. Effect of SS and CRL on Compaction Parameters.

The variations of water content with dry density for soil samples mixed with various percentages of SS or CRL individually or together are shown in Figures (7 to 9). The values of maximum dry density (MDD) and optimum moisture content (OMC) of the natural soil were found to be 17.66 kN/m^3 and 17.4%, respectively. It can be noticed from Figure (7) that, the value of MDD was increased to 18.79kN/m^3 and the value of OMC was decreased to 11.85% with the addition of 20% SS to the expansive soil samples. Whereas, with the addition of CRL up to 15%, the value of MDD was increased to 18.25kN/m^3 and the value of OMC was decreased to 15% from of those natural soil. But, with the increase of CRL up to 20%, the value of MDD decreased to 18.15 kN/m^3 and the value of OMC increased to 15.8%, as shown in Figure (8).

Figure (9) shows that with the addition of 10% SS+10% CRL to the expansive soil samples, the value of MDD increased by 7.5% and the value of OMC reduced by 37.2%. Whereas, with the addition of 20% SS+15% CRL to the expansive soil samples, the value of MDD increased by 8.7% and the value of OMC reduced by 41.4%. The increase in MDD value with the increase in the SS and CRL contents is associated with the SS and CRL particles, which are heavy weight materials because of its high specific gravity compared to the natural soil samples. Also, due to its lower adsorption of water SS and CRL causes the decrease in the diffused double layer thickness and brings the particles closer to each other and hence, the value of MDD increases. Therefore, using the same amount of compaction effort, the particles pack together and the dry density increases. Consequent on particles becoming closer and decreased water holding capacity, the OMC values were decreased.

4.3. Effect of SS and CRL on Swelling Characteristics

Figure (10) shows that, with the addition of 20% SS or 20% CRL for 28 days of curing period individually the values of swelling pressure were decreased by 44.1% and 59% respectively, and the values of swelling percent were decreased by 45% and 64.8% respectively.

However, the addition of the mixture of 10% SS+10% CRL and 20% SS+20% CRL at 28 days of curing durations individually resulted in reductions of swelling pressure by 69.6% and 85% respectively. Moreover, the addition of the mixture 10% SS+10% CRL and 20% SS+20% CRL for 28 days of curing periods individually resulted in reductions of swelling percent by 84.3% and 93% respectively, as shown in Figure (11). It is well-known that, the decrease in the values of swelling pressure and swelling percent of an expansive soil is influenced by many factors, such as clay mineral composition, amount of non-clay material present, density, void ratio, and cementation. So that the decrease in the values of swelling characteristics is evident due to the presence of steel slag and crushed limestone (non-clay materials) which reduces the clay-mineral content per unit mass of the mixture, or that the total surface area of expansive clay particles.

4.4. Effect of SS and CRL on California Bearing Ratio (CBR).

California Bearing Ratio (CBR) is a penetration test for a comprehensive evaluation of the mechanical strength of road subgrades and base courses. To investigate the CBR value, the samples were prepared at the optimum moisture content, which obtained from the modified Proctor compaction test, and the samples were soaked for 7 days. It can be noticed in Figure (12) that, both stabilizers SS and CRL were effectively worked and caused notable increases in the magnitude of CBR. Hence, using 20% SS showed in higher CBR value by 9.3 % compared with using 15% of CRL. This is due to SS additive has rich composition of raw iron. Also Figure (12) shows that, the values of CBR increased from 3.4% to 26.7% with addition of the mixture 10% SS+10% CRL to the expansive soil samples and from 3.4% to 39.5% with 20% SS+15% CRL mixture added together. The outcome of the mix (SS-CRL) is higher by (8-20) % compared to the SS outcome separately.

The increase in CBR value is may be due to the role of the iron material in the SS in addition to the capability of the CRL to increase the cementing bonds among soil particles. Hence, both SS and CRL played their role to either add new capable particles in terms of friction and new capable particles in terms of cohesion. Newly created bonds tighten the soil particles strongly together, which increase the strength and then CBR value.

5. Conclusions

Based on the results of tests, the following conclusions are drawn:

1- The values of liquid limit, plastic limit, plasticity index, and linear shrinkage limit were decreased by adding SS and CRL from 0% to 20% separately or together to the expansive soil samples.
2- By the addition of 20% SS, the value of MDD was increased to 18.83 kN/m^3, and the OMC was decreased to 11.85% from those of natural soil of MDD= 17.66 kN/m^3 and OMC= 17.4%, respectively.
3- By the addition of CRL up to 15% the values of MDD were increased to 18.25kN/m^3 and the OMC values were decreased to 15% from those of natural soil. Whereas, with the increase of CRL content to 20% the value of MDD decreased to 18.15 kN/m^3 and the value of OMC increased to 15.80%.
4- With the addition of 10% SS+10% CRL, the value of MDD increased by 7.5% and the value of OMC reduced by 37.2%. Whereas, with addition of 20% SS+15% CRL, the value of MDD increased by 8.7% and the value of OMC reduced by 41.4%.
5- Both of swelling pressure and swelling percent were decreased by 44.1% and 59% respectively with the addition of 20% SS, and decreased by 59% and 64.8% respectively with the addition of 20% CRL for 28 days of curing period.
6- The addition of the mixture 10% SS+10% CRL for 28 days curing periods, resulted in reductions of swelling pressure and swelling percent by 69.8% and 84.3% respectively. Whereas, with the addition 20% SS+20% CRL, these ratios decreased by 85% and 93% respectively.
7- With the addition of 20% SS and 15% CRL individually, the values of CBR were increased from 3.4% to 18.7% and from 3.4% to 9.4% respectively.
8- With the addition of the mixture 10% SS+10% CRL and 20% SS+15% CRL individually, the values of CBR increased from 3.4% to 26.7% and from 3.4% to 39.5% respectively.

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دراسة تجريبية للتربة الانتفاخية المثبتة بخبث الفولاذ والحجر الجيري المطحون

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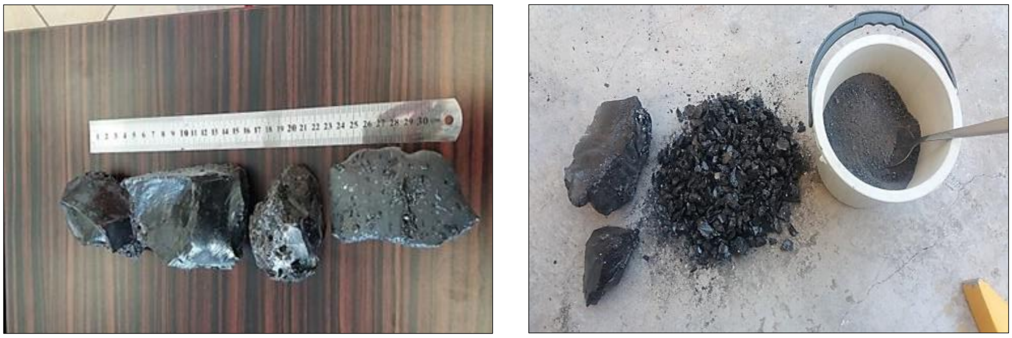
المستخلص

تناولت هذه الدراسة تقييم آثار خبث الفولاذ (SS) والحجر الجيري المطحون (CRL) على الخواص الجيوتقنية للتربة الانتفاخية. وأجريت سلسلة من الاختبارات المختبرية على التربة الطبيعية والمثبتة. وتمت إضافة كل من SS و CRL بنسبة 0 ، 2.5 ، 5 ، 10 ، 15 ، و 20% إلى التربة الانتفاخية المستخدمة. ان الاختبارات التي أجريت تتضمن: حدود القوام ، الوزن النوعي ، تحليل الهايدروميتر ، رص بروكتور المعدل ، ضغط الانتفاخ ، نسبة الانتفاخ ، ونسبة تحمل كاليفورنيا (CBRالمشبعة). أظهرت النتائج أن كلا من حد السيولة ومؤشر اللدونة ومحتوى الرطوبة الأمثل قد انخفضت. مع إضافة الخليط المتكون من 10% SS مع 10% CRL والذي عولج لمدة 28 يوم ، انخفضت قيم ضغط الانتفاخ ونسبة الانتفاخ بنسبة 69.8% و 84.3% على التوالي. ومع ذلك ، حيث زادت قيم كثافة الجفاف القصوى (MDD) من kN/m3 17.66 إلى 18.79 kN/m3 ومن 17.66 kN/m3 إلى 18.25 kN/m3 مع إضافة 20% SS و 15% CRL على التوالي. أيضا ، مع إضافة الخليط 10 SS% CRL +10% و 20 SS% CRL + 15 % بشكل فردي ، ارتفعت قيم CBR من 3.4 % إلى 26.7 % ومن 3.4 % إلى 39.5 % على التوالي. ومن خلال هذه الدراسة تم التوصل الى ان خبث الفولاذ والحجر الجيري المطحون يمكن ان يساهم بنجاح في تحسين الخصائص الجيوتقنية للتربة الانتفاخية.

الكلمات المفتاحية : التربة الانتفاخية ، تثبيت التربة ، خبث الفولاذ ، الحجر الجيري المطحون ، CBR ، UCS ، الانتفاخ.

Table 1: Engineering properties of tested expansive soil. (Source: Researcher)

NO.	Properties		Value
1	Particle Size Distribution	Sand (%)	14
2		Silt (%)	44
3		Clay (%)	42
4	Atterberg Limits	Liquid Limit (LL) (%)	62.05
5		Plastic Limit (PL) (%)	30.10
6		Plasticity Index (PI) (%)	31.95
7		Linear Shrinkage Limit (LS) (%)	15.86
8	Soil type according to the Unified Soil Classification System (USCS)		CH
9	Specific Gravity (G_s)		2.76
10	Clay Activity		0.652
11	Compaction Characteristics	OMC (%)	17.4
12		MDD (kN/m^3)	17.66
13	Swelling Percent (%)		8.73
14	Swelling Pressure (kPa)		185.1
15	Degree of expansion		High
16	Unconfined Compressive Strength (UCS) (kPa)		474
17	Soaked CBR (%)		3.4



(a) (b)

Fig. 1: The used steel slag in the laboratory tests, A-Large particle size, and B-crushed and powdered. (Source: Researcher)

Fig. 2: Crushed and sieved limestone. (Source: Researcher)

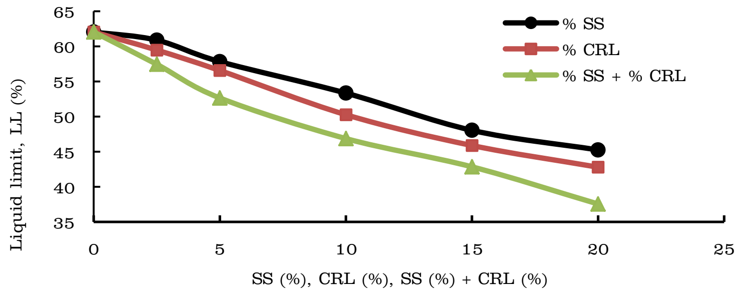


Fig. 3: Variation of liquid limit with percentages of SS and CRL. (Source: Researcher)

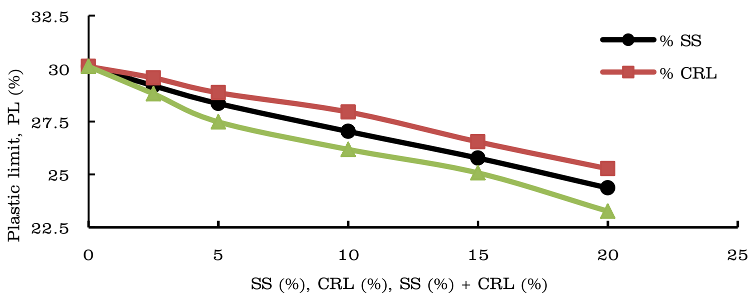


Fig. 4: Variation of plastic limit with percentages of SS and CRL. (Source: Researcher)

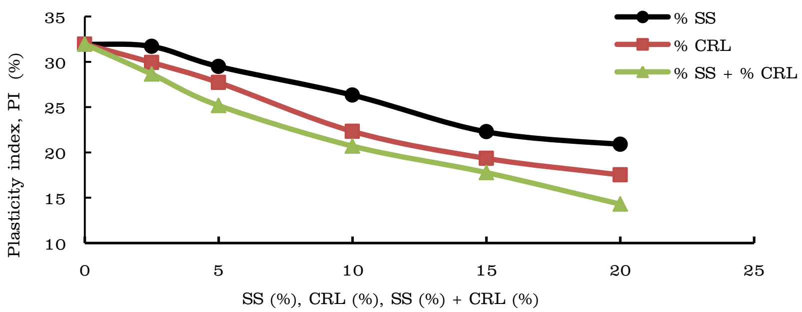


Fig. 5: Variation of plasticity index with percentages of SS and CRL. (Source: Researcher)

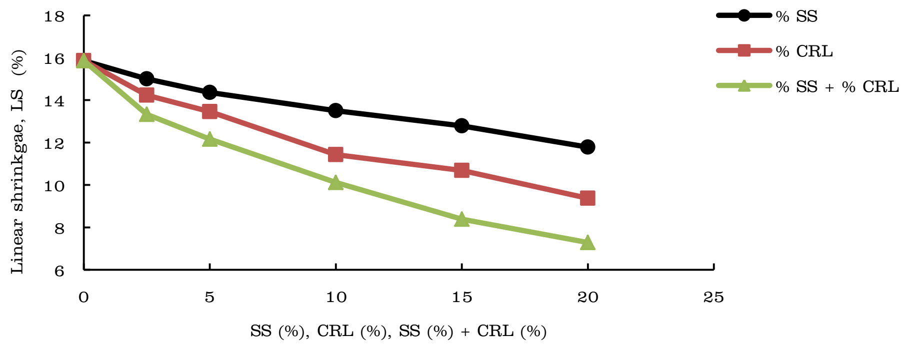


Fig. 6: Variation of linear shrinkage with percentages of SS and CRL. (Source: Researcher)

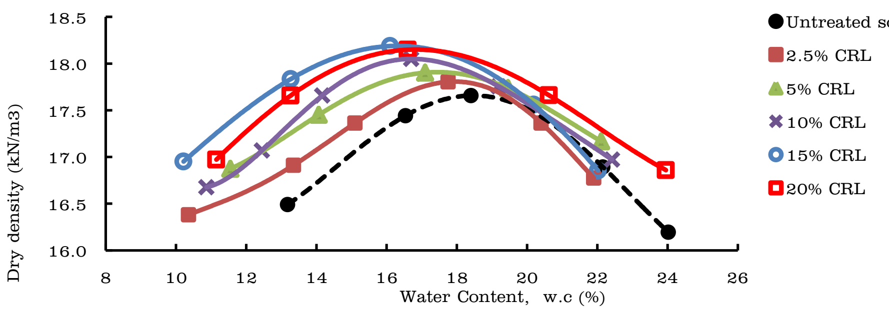


Fig. 7: Compaction characteristics curves of natural and stabilized soil with SS. (Source: Researcher)

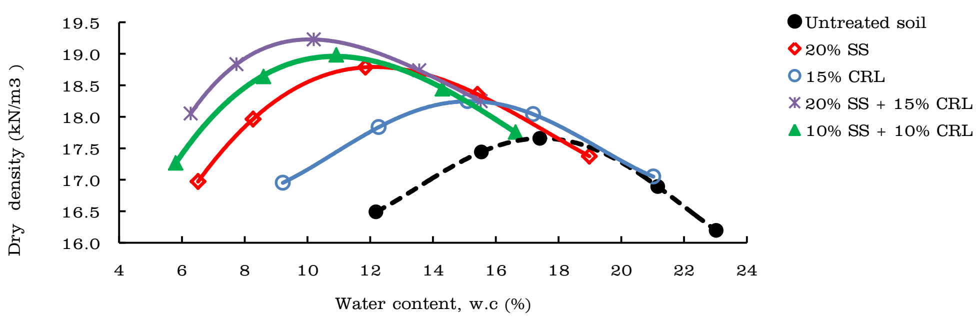


Fig. 8: Compaction characteristics curves of natural and Stabilized soil with CRL. (Source: Researcher)

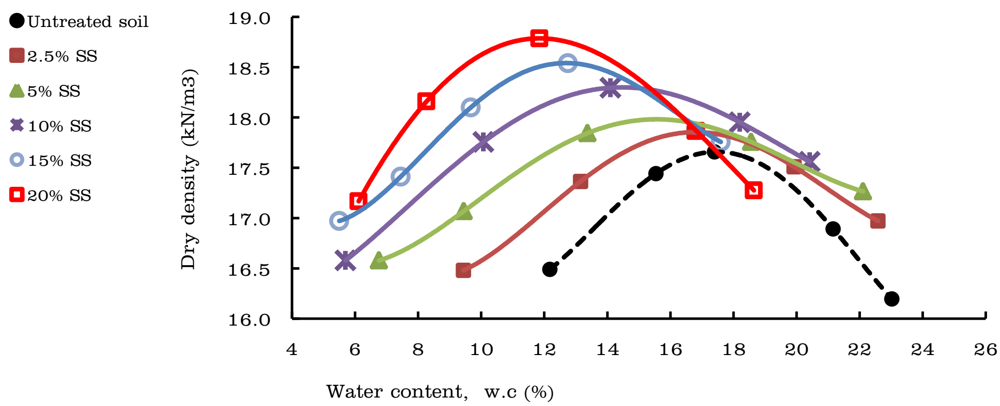
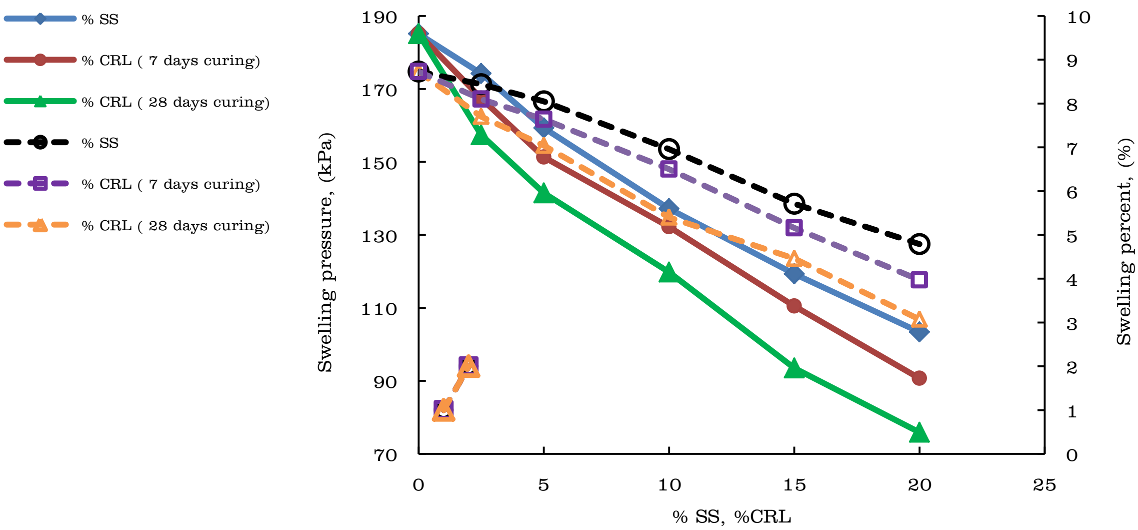


Fig. 9: Variation of water content with dry density for soil samples mixed each of SS and CRL together. (Source: Researchers)



Swelling Pressure: Solidline (▬)
Swelling Percent: Dashline (---)

Fig. 10: Variation of swelling pressure and swelling percent with percentages of SS and CRL. (Source: Researchers)

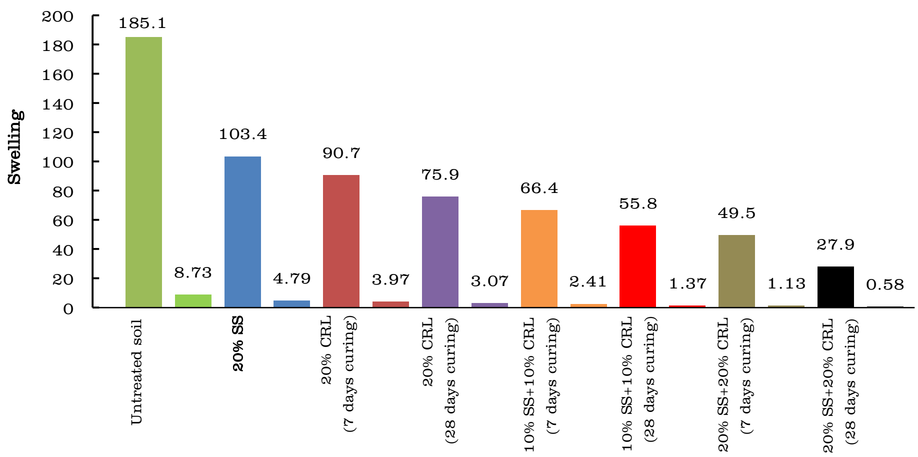


Fig. 11: Comparison between the effect of SS and CRL on the swelling Pressure and swelling percent. (Source: Researchers)

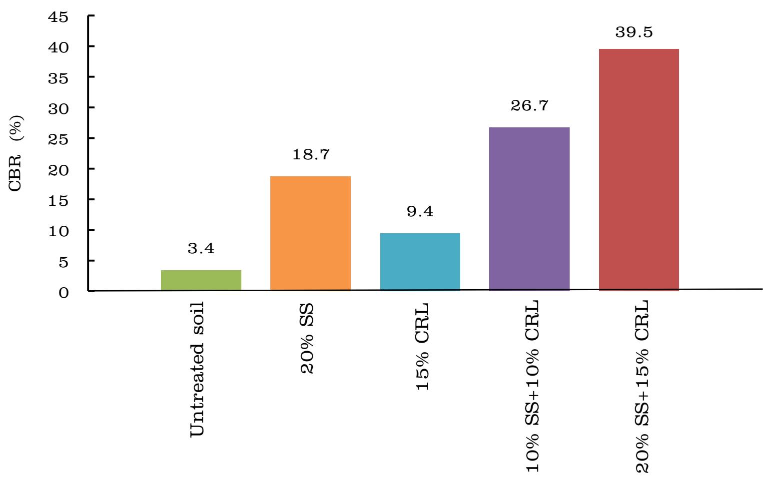


Fig. 12: Variation of CBR values with percentages of SS and CRL. (Source: Researchers)