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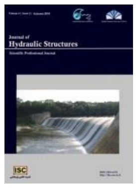

Effect of rice husk ash on the swelling pressure of bentonite soil stabilized with lime in the presence or lack of sulfate

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Abstract
Lime is an effective substance to decrease the swelling of expansive soils. The effective use of lime as a stabilizing agent in the presence of sulfate under some circumstances has been questioned due to the formation of ettringite. In this research, the effect of the addition of rice husk ash (RHA) on the swelling pressure of a bentonite soil (B) modified with lime (L) and calcium sulfate or gypsum (G) was investigated. Nine groups of twin compacted samples, namely, bentonite soil (B), B + L (3% by dry weight), B+3%L+ 5%G, B+3%L+RHA (5, 10 and 15% by dry weight, respectively) and B+3%L+5%G+RHA (5,10 and 15%, respectively), were prepared and tested immediately for 1-D constant volume swelling pressure measurements. Similar groups of samples were prepared and tested after 7 and 28 days of curing. The results indicated the effect of RHA in decreasing the magnitude of swelling pressure in comparison with untreated and treated soil without RHA.

Keywords: Rice husk, Lime, Sulfate, Expansive soil, Swelling pressure.

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1. Introduction

The stabilization of expansive clay soils with cementitious materials such as ordinary Portland cement and lime has been practiced over the past six decades (e.g. [1-8]). The decrease in swelling potential of treated soils with lime is due to the flocculation of soil particles as a result of exchanging Ca2+ cations with other cations present on the surface of the clay minerals, which causes a reduction in tendency for double layer expansion. The second reason for the decrease in swelling potential upon blending lime or cement with expansive soils is due to pozzolanic reactions that occur with time between silicates and aluminates that are detached from the surface of clay minerals and calcium ions present in the solution. The silicates and aluminates are dissociated from the clay mineral surfaces when under alkaline conditions

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(pH>12) in the presence of lime or cement in excess of 3% of the soil dry weight [9].

Occasionally, the use of lime or cement for treating expansive soils rich in sulfate-bearing minerals has caused more expansion. This expansion is due to the formation and subsequent hydration of minerals ettringite and / or thaumasite. The Ca2+ ions in the calcium-based stabilizers participate with alumina released from clay minerals and with sulfate in the presence of water to form ettringite and/or thaumasite [10-17]. Pakbaz and Keshani [18] showed that the presence of 5 to 10% of gypsum caused the initial generation of higher magnitudes of swelling pressure compared with those of untreated bentonite soil and bentonite soil treated with 3% of lime.

In several countries such as Iran, India, and Thailand, there are many agricultural waste materials produced, such as rice husk (RH) that are mostly dumped or used as fuel. Rice husk is produced during the milling process of rice and consists approximately 22% of the weight of the rice (Rice Market Monitor, FAO) [19]. The production of RH amounts to approximately 742 million tons annually (http:www.ricehuskash.com). The RH that remains after burning at 650°C consists mainly of silica dioxide (SiO2), which is very reactive with lime (e.g. [20-22]). The reactivity of RHA toward lime is strongly dependent on the temperature at which the ash is produced [23]. They have shown that RHA is most reactive with lime when burned at 500°C. They also indicated that RHA free from cationic impurities showed a higher reactivity. In fact, Real et al. [24] showed that when RH was leached with HCl before burning at 600°C, the remaining ash was approximately 260 times finer than when it was not leached. The authors also indicated that the leaching of RH before burning produces the remaining ash that is free from cationic impurities, which make the RHA coarser when they are present.

Muntohar and Hantoro [22] showed that increases in the plastic and liquid limits of the expansive soil modified with lime increases the RHA content, whereas a decrease in the liquid limit and an increase in the plastic limit occurred when RHA was added to natural soil. The reason for the increase in limit values may be due to the porous nature of the RHA particles, as reported by Viet-Thin-An [25]. Muntohar and Hantoro [22] also showed a decrease in the swelling pressure of soil stabilized with lime with the addition of RHA.

The practical application of the magnitude and time rate of the swelling pressure for clay shale was addressed by Mesri et al. [26]. The effect of lime on the swelling pressure of an expansive bentonite soil in the presence of sulfate has been studied by Pakbaz and Keshani [18]. The effect of RHA as a pozzolan has not been tested in the presence of lime and sulfate together before in expansive clays. In this research, the effect of RHA on the swelling pressure of lime-treated bentonite soil in the presence of sulfate is studied. Three different percentages of RHA together with lime and gypsum are mixed with bentonite soil to investigate the effect of RHA.

2. Materials and methods

2.1. Bentonite soil

Bentonite used in this research was supplied from Kashan Doreen factory in Iran. For better mixing, bentonite was first passed through a No. 40 US sieve before it was tested according to the ASTM D4318-10e1 [27] procedure for determining the Atterberg Liquid and Plastic Limits, which were measured to be 179% and 36%, respectively. The chemical compositions of bentonite are summarized in Table 1.

Table 1 Bentonite chemical composition

Compound	SiO_2	Al_2O_3	Fe_2O_3	K_2O	CaO	MgO	SO_3	P_2O_5	TiO_5	L.O.I
%	60.26	10.8	2.45	0.84	1.23	1.32	0.46	0.1<	0.17	2.2

2.2. Lime

The lime used in this research was industrial hydrated lime. The chemical compositions of lime is shown in Table 2. The lime was passed through a No. 200 US sieve before mixing with the soil.

Table 2 Lime chemical composition

Compound	$C_a(OH)_2$	MgO	L.O.I
%	93.27	0.81	5.92

2.3. Gypsum (calcium sulfate)

The gypsum used in this research was obtained from Semnan gypsum factory located at Semnan industrial city in north east Iran. This material has the lowest solubility but is the most common sulfate present in most natural soils. The chemical composition of gypsum is shown in Table 3.

Table 3. Gypsum chemical composition

Compound	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	L.O.I
%	0.7	0.26	0.11	38.55	0.26	55.68	4.44

2.4. Rice husk ash (RHA)

In this research, the rice husk was obtained directly from rice farms located in Mazandaran Province in northern Iran. The rice husk was burned in two stages before mixing with soil. In the first stage, it was burned in the open space for approximately 40 min. Then, to burn the remaining carbon from the ashes, the remaining ashes were collected and placed in an electric kiln at a temperature of 650°C and maintained for 90 min. The grain size distribution of RHA after the burning process showed that most of the RHA particles remained on the No. 200 US sieve (d85=0.35mm; d50=0.15mm and d15=0.074mm). The initial preliminary tests to examine the effect of RHA size on reactivity during hydration and pozzolanic reactions showed that the RHA particles that were ball milled and passed through the No. 200 US sieve before mixing with soil were more effective in decreasing the swelling pressure of bentonite than those particles that remained on the No. 200 US sieve. Therefore, it was decided that for all tests, the above procedure for the preparation of RHA particles before mixing was to be followed. However, it is recognized that ball milling of RHA may not be economical for field applications. Pre-leaching of RH before burning at a burning temperature of approximately 500°C may be an appropriate method for obtaining RHA with a much higher surface area [23,24]. The chemical compositions of RHA is shown in Table 4.

Table 4. Rice husk ash Chemical composition

Compound	SiO_2	La&Lu	MnO	P_2O_5	SO_3	MgO	CaO	K_2O	Fe_2O_3	Al_2O_3	L.O.I
%	83.0	>1	0.17	5.6	0.34	2.0	1.5	3.8	2.0	0.27	1.28

2.5. Prepration of samples

To compare the results of the swelling pressure tests and to observe the effect of RHA on different samples, several series of samples were prepared according to the following procedure. All samples were mixed and compacted at the respective optimum water content to maximum dry density according to the standard proctor compaction procedure. For each series of samples, three groups of samples were prepared. One group was measured for swelling pressure immediately after the mixing process. The other two groups were tested after 7 and 28 days of curing. After compaction, the latter group of samples was wrapped in plastic bags and maintained at room temperature under 100% humidity for the required curing period. A total of 9 series of samples, namely, B, B+3%L, B+3%L+5%G, B+3%L+(5,10, and 15%)RHA, and B+3%L+5%G+(5,10, and 15%)RHA was tested without curing and a total of 16 series of samples was tested after 7 and 28 days of curing. In each group, 2 similar samples were tested, and the average results were reported.

The cured and uncured compacted samples were trimmed into consolidation rigid rings that were 70 mm in diameter and 20 mm in height before placing in an oedometer and mounting the samples in a consolidation front loading device for constant volume swelling pressure testing. The constant volume swelling pressure tests were performed according to the ASTM D4546-96 standard [28]. According to this standard, the purpose is to find the pressure needed to apply to the sample in order to maintain the original height of sample after inundation.

3. Results and discussions

3.1. Effect of RHA on the compaction curves

Figures 1 and 2 show the effect of RHA on the compaction curves of treated bentonite with lime and lime + gypsum. In general, RHA caused a decrease in the maximum dry density and an increase in optimum water content of treated bentonite samples. The decrease in maximum dry density was approximately 4-9% that may be due to the reduced specific gravity of the RHA particles compared with that of the treated bentonite. The increase in the optimum water content was approximately 25-36%, which may be due to the porous nature of the RHA particles, as mentioned earlier.

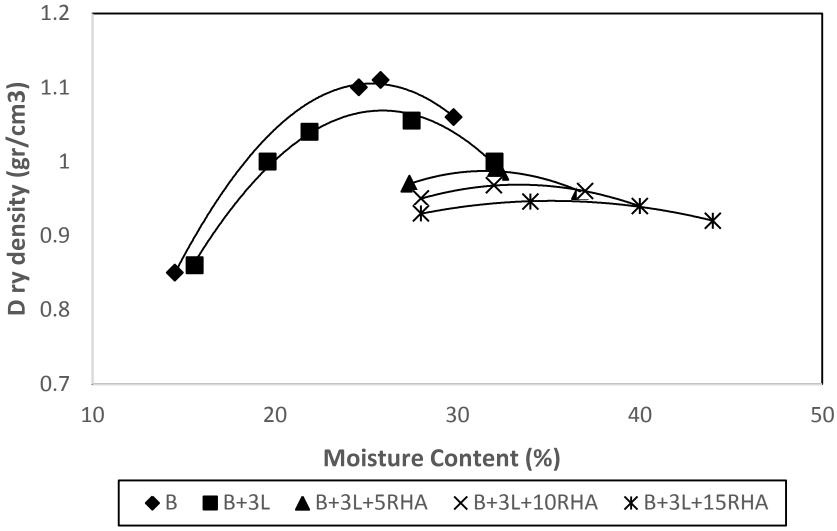

Figure 1. Effect of the RHA on compaction curve of soil stabilized with lime

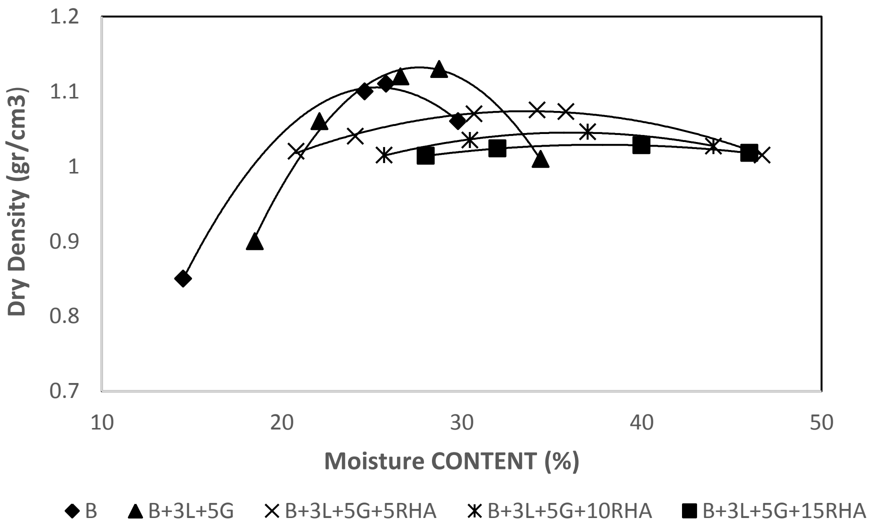

Figure 2. Effect of RHA on compaction curve of the soil stabilized with lime in the presence of sulfate

3.2. Effect of rice husk ash on the swelling pressure of B+3%L

Figure 3 shows the effect of RHA on the swelling pressure of lime-treated bentonite soil tested immediately after mixing and compaction with no curing period. The swelling pressure decreased with an increasing amount of RHA from 210 kPa to 168, 147 and 136 kPa for 5, 10 and 15% RHA, respectively (Table 5). These results mean that the addition of RHA has caused an approximately 20 to 35% decrease in the swelling pressure of lime-treated bentonite soil. This decrease in swelling pressure with no curing period is due to the increase in void ratios (higher optimum water content and lower maximum dry density) caused by the presence of RHA in samples as well as to a reduced tendency for double layer expansion as the result of the addition of RHA.

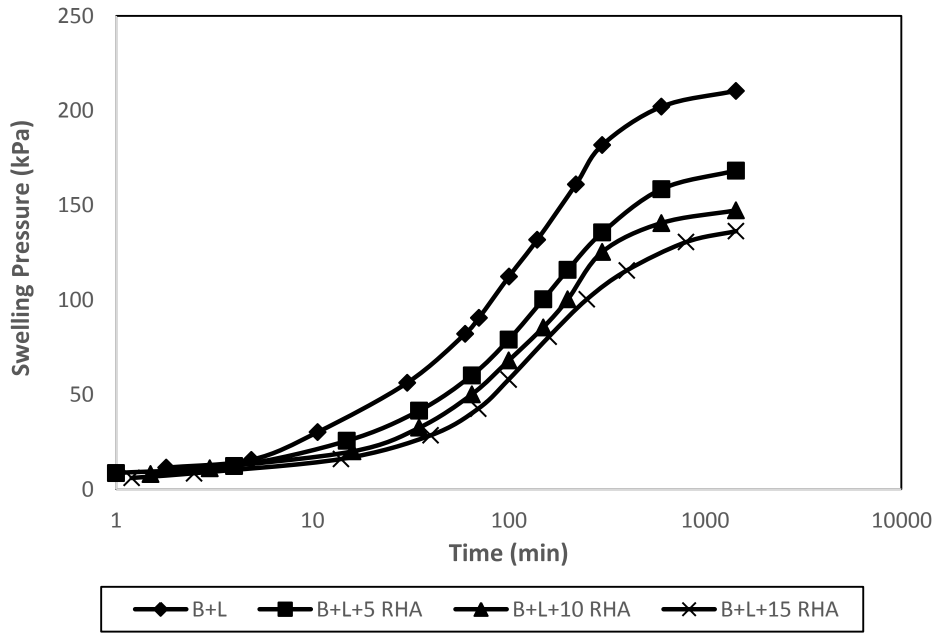

Figure 3. The effect of RHA on swelling pressure of soil stabilized with lime measured immediately after mixing

Figure 4 shows the effect of RHA on the swelling pressure of lime-treated bentonite soil after a 7-day curing period. The swelling pressure of lime-treated bentonite soil after 7 days of curing was 150 kPa, which decreased to 100, 82 and 51 kPa for RHA contents of 5, 10, and 15%, respectively (Table 5); a decrease of approximately 33 – 66%. This decrease in swelling pressure of lime-treated bentonite soil was due to the additional cementing effect of chemical products of pozzolanic reactions that occurred between lime and RHA.

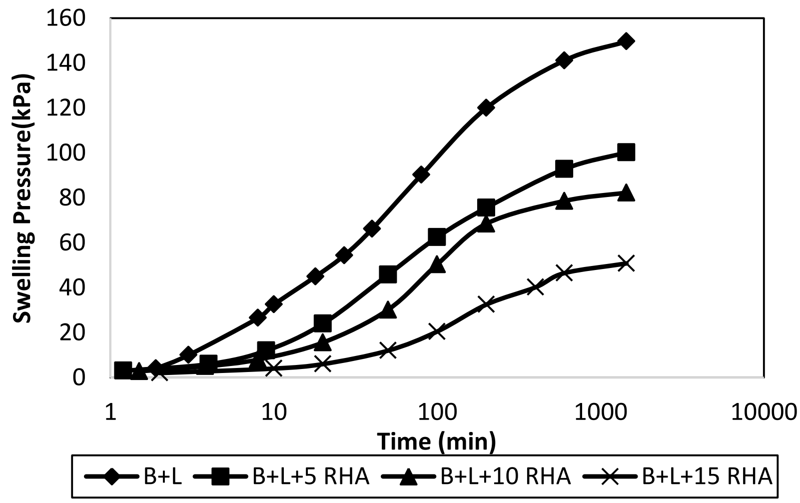

Figure 4. The effect of RHA on swelling pressure of soil stabilized with lime after 7 days of curing .

Fig. 5 shows the effect of the curing period on the swelling pressure of B+3%L+ 15%RHA samples. A decrease of 63-82% for curing periods of 7 and 28 days was observed compared to samples with no curing period (see also Table 5).

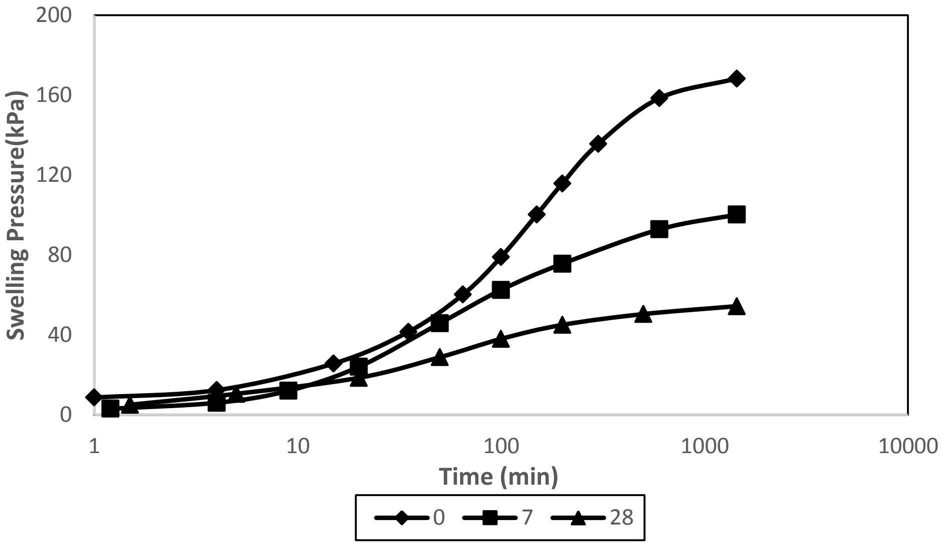

Figure 5. Effect of curing time on swelling pressure of soil stabilized with 3% of lime and 15% of RHA

Table 5 summary of final swelling pressures measured (in kPa)

Samples	Uncured	7days Curing	28days Curing
B pure	367	-	-
B + 3% L	210	149	91
B + 3% L + 5% RHA	168	100	54
B + 3% L + 10% RHA	147	82	40
B + 3% L + 15% RHA	136	51	25
B + 3% L + 5% G	267	124	39
B + 3% L + 5% G + 5%RHA	200	74	30
B + 3% L + 5% G + 10%RHA	183	66	18
B + 3% L + 5% G + 15%RHA	166	57	11

3.3. EFFECT OF RHA ON THE SWELLING PRESSURE OF B+3%L+5%G

Fig. 6 shows the swelling pressures of B+3%L+5%G without and with RHA at different contents with no curing period. The results indicate that the sample of B+3%L+5%G with no RHA showed a higher swelling pressure than that of sample B+3%L. The higher swelling pressure may be due to the formation of ettringite. However, the addition of RHA to this group of samples caused a decrease in the swelling pressure. The swelling pressures for this group of samples were measured to be 200, 183 and 166 kPa for RHA contents of 5, 10 and 15%, respectively, (see also Table 5) which means a decrease of 25 – 37% compared with the samples with no RHA. The decrease in the swelling pressure in this case may be due to a higher water content and void ratio for these samples as well as a lower tendency for an expansion of the double layer as a result of the presence of RHA. When the values of the swelling pressure for the B+3%L+5%G+RHA samples with no curing are compared with those for the samples of B+3%L+RHA (see Table 5), the effect of both ettringite formation and a reduced void ratio for the former samples may be responsible for the higher values of the former group. According to

Table 5, curing periods of 7 and 28 days caused further decrease in swelling pressure of approximately 40 to 72% for these samples compared with those of the samples without RHA. In this case, a further decrease in the swelling pressure with curing may be due to the cementing effect of additional chemical products generated as a result of pozzolanic reactions that have occurred between the RHA and lime.

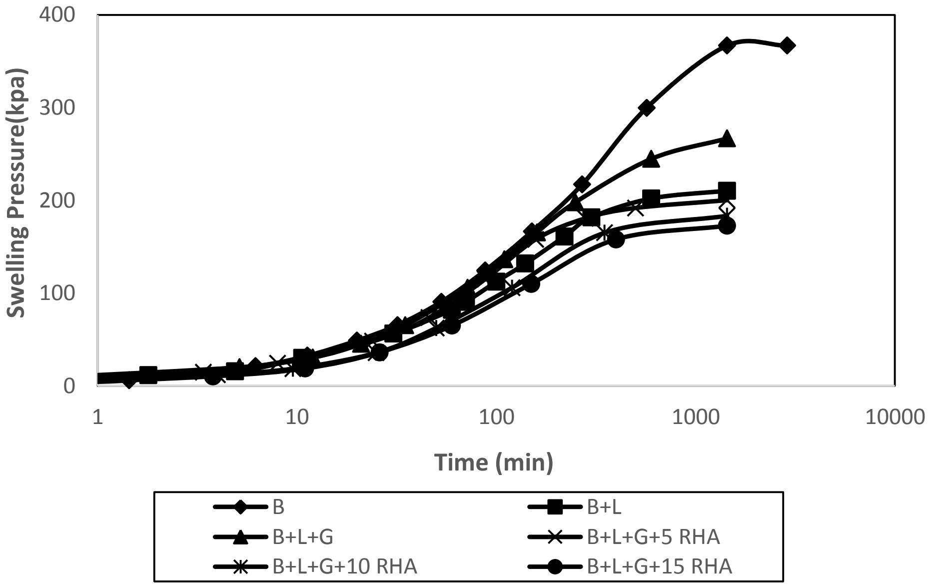

Figure 6. Effect of RHA on swelling pressure of lime treated soil in the presence of sulfate with no curing

4. Conclusions

The following conclusions are reached with regard to soil index properties, compaction characteristics and value of constant volume swelling pressure after examinations of different groups of bentonite soil mixtures with 3% of lime + 5% of gypsum and 5, 10 and 15% of rice husk ash.

1. The addition of RHA to soil stabilized with lime lowered the maximum dry density and increased the optimum moisture content.
2. The addition of gypsum to soil stabilized with lime increased the maximum dry density and decreased the optimum moisture content. The addition and increasing the amount of RHA to the stabilized soil with lime and gypsum decreased the maximum dry density and increased the optimum moisture content.
3. The rice husk ash particles that passed through the No. 200 US sieve were more effective in reducing swelling pressure of bentonite than those remaining on the No. 200 US sieve. A more economical procedure for reducing the size of RHA is preleaching with acid before the burning process.
4. Rice husk ash is a suitable additive to reduce the swelling pressure. The addition of RHA to stabilized soil with lime decreased the swelling pressure. The optimal

amount for stabilized soil with lime and RHA is to add 15% RHA during 7 days of curing.

5. Rice husk ash is a suitable additive to lower the detrimental effect of sulfate presence in lime-treated expansive soil.

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