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Stability Behavior of Lime Stabilized Gypseous Soil

Abdulrahman Aldaood
Centre de Recherche sur la Matière Divisée, CRMD, FRE CNRS 3520, Orléans/ France
Email:abdulrahman.aldaood@cnrs-orleans.fr
Marwen Bouasker
Centre de Recherche sur la Matière Divisée, CRMD, FRE CNRS 3520, Orléans/ France
Email:marwen.bouasker@cnrs-orleans.fr
Amina A Khalil
Civil Engineering Department-College of Engineering-Mosul University, Mosul/ Iraq
Email: amina.alshumam@gmail.com
Ibrahim Al-Kiki
Water Resources Engineering Department,College of Engineering-Mosul University, Mosul/ Iraq
Email: ialkiki@yahoo.com

ABSTRACT

In arid and semi-arid zones, gypsum (CaSO4.2H2O) is one of the soluble of the common minerals that found in soils. In Iraq, gypseous soils is a worldwide stability problem that causes extensive damage upon wetting, and occur in certain areas characterized by variation of climatic conditions. The results of the stability behavior of lime stabilized gypseous soil where present in this paper under different tests. These tests were erosion, leaching and soaking. Erosion test was conducted under different variables such as water temperature, water velocity and flow duration. The soil used in this study was taken from a site near Al – Hader district about (80 km) from Mosul city. Its main geotechnical index properties are liquid limit is (46%), plastic limit (22%) and specific gravity is 2.58. The amount of the gypsum was 20%. The soil samples were treated with optimum lime percent (4%) depending on the Illinois procedure. A gypseous soil with 20% gypsum content was used and stabilized with 4% lime. All stabilized soil samples were cured for 2 days at 49^0 C. The results indicate that, the loss in weight increased for samples subjected to the flowing water, further increase in weight losses with increasing flow duration. High water velocity causes increasing in weight losses and loss in gypsum content , more loss in weight and more loss in gypsum content, for all values of flow duration and water temperature. Unconfined compressive strength decreased during the soaking process and further decrease in strength with increasing soaking duration. The leaching effect causes a continuous increasing in the permeability value of unstabilized soil samples, while it has an insignificant effect on the permeability of lime stabilized soil samples. Leaching

is a time-dependent process. The results showed that the pH values of natural and lime stabilized soil samples decreases during leaching process.

Keywords: Gypseous Soil, Lime Stabilization, Erosion, Leaching, Permeability, Gypsum Dissolution, Loss in Weight

سلوك استقرارية التربة الجبسية المثبتة بالنورة

الخلاصة

تتميز التربة الجبسية بانتشارها في المناطق الجافة وشبه الجافة. إن زيادة نسبة الجبس داخل التربة تسبب أضرار ومشاكل هندسية أحياناً تكون بالغة تؤدي إلى انهيار المنشآت المقامة على مثل هذه التربة عند تعرضها للماء. شملت هذه الدراسة اختبار ثبوتية التربة الجبسية المثبتة بالنورة تحت فحوصات مختبرية مختلفة. تضمنت هذه الفحوصات, فحص التعرية, فحص الغسل وفحص الغمر. أجري فحص التعرية تحت تأثير متغيرات عديدة منها: درجة حرارة الماء, سرعة الماء وفترة الجريان. أما بالنسبة لفحص الغسل والغمر فقد اجري كل منهما بأوقات مختلفة. في هذه الدراسة اختيرت تربة جبسية ذات محتوى جبسي (20%) من احدى الأماكن القريبة لمنطقة الحضر, التي تبعد حوالي (80 كم) عن مركز مدينة الموصل. تم تثبيت نماذج التربة الطبيعية بنسبة (4% نورة) والتي تم إيجادها اعتمادا على طريقة إلينويز. أنضجت النماذج المثبتة بالنورة بدرجة حرارة (49) درجة مئوية ولمدة يومين. أظهرت نتائج فحص التعرية, حصول فقدان بالوزن نتيجة التعرض للماء الجاري, اذا تزداد نسبة الفقدان بالوزن مع زيادة فترة الجريان ودرجة حرارة الماء. كذلك سببت سرعة الجريان حصول زيادة في نسبة نقصان كل من بالوزن ونسبة الجبس. أيضا سببت عملية الغمر بالماء حصول نقصان في مقاومة الانضغاط غير المحصور لنماذج التربة المثبتة بالنورة, اذ ازداد مقدار النقصان في مقاومة هذه النماذج مع زيادة فترات الغمر. كذلك كان تأثير الغسل على نفاذية التربة الطبيعة غير المثبتة بالنورة سلبيا ومشابهاً لتأثير الغمر على مقاومة الانضغاط غير المحصور. اذا ازداد معامل نفاذية التربة الطبيعية مع الوقت وتحت تأثير عملية الغسل. في حين أظهرت نماذج التربة المثبتة بالنورة مقاومة جيدة لعملية الغسل, اذ كان تأثير هذا المعامل قليل وغير مؤثر مقارنة مع نماذج التربة الطبيعية. أخيرا قلت قيمة الرقم الهيدروجيني لنماذج ماء الراشح للتربة الطبيعية والمثبتة خلال عملية الغسل.

INTRODUCTION

Gypseous soils are currently used extensively in geotechnical applications especially in the infrastructures constructions, like highways and pavements. The amount of gypsum in a soil is crucial in determining its properties required for all geotechnical applications, especially volume change and strength. The stability and durability properties of natural soil can be improved by chemical stabilization. Chemical stabilization of soils involves additives such as cement, lime and other chemical additives. Lime stabilization is one of the most economical techniques to improve the engineering behavior of gypseous soils.

Gypseous soils usually represent in arid and semi-arid areas of the world, these soils occupy about 20% of the total area in Iraq, which is equivalent to about 7.3% of the

total area of gypsiferous soils in the world (FAO, 1990). Gypseous soils have been often used recently as construction materials in foundation base of building structures and in pavement layers. In dry state, gypsum is considered as a bonding agent that will increase the shear strength and reduce the compressibility of the soil (Salas et al. 1973). In soil mechanics one of the most important factors taken into account is the effect of water on the geotechnical properties of gypseous soils.

Gypseous soils are problematic soils from the engineering points of view, especially upon wetting. Most hazards which are related to construction on gypseous soils occurred when these soils subjected to water, causing softening of soils and reducing the shear strength (Razouki and El-Janabi 1999; Albusoda 1999; Ismail and Hilo 2008; Al-Dabbas et al, 2010). Gypseous soils are highly soluble materials in their nature, and the types of problems associated with it. The failures include collapse and settlement, which can affect all construction including buildings (Arutyunyan and Manukyan, 1982; Cooper 1998 and 2008), roads (Ahmed, 1985; Abin et al., 1998; Hua et al., 2010) and other engineering structures. Damages and movements sourced from gypseous soils generally occur relatively slowly. Sometimes the damages from these soils are minor maintenance and aesthetic concerns, but often they are much worse even causing major structural distress. Different structures damages that were founded on gypseous soils were noticed in Iraq (Taha, 1979; Al-Saffar, 2000). The most severe problems face geotechnical and foundation engineers, when constructing hydraulic structures on gypseous soils. It is associated with settlement problems with the presence of water; the existence of cracks assists the flow of water and thus causing to dissolve the gypsum in the soil layers.

Gypsum dissolution affected by many factors: Salinity, pH, temperature of water, and the rate and velocity of water flow (Fookes et al., 1985; Obika et al., 1989; Keren and Connor, 1982; Al-Zubaydi, 2011). James and Lupton (1978) show the important of the temperature, salinity and flow rate in gypsum solution. They also worked on developing models to predict the rate of gypsum dissolution as a function of the various variables controlling it.

In order to improve the engineering behavior of soils, several improvement techniques are available in geotechnical engineering practice, on of this are lime stabilization method. This method well used to improve the engineering properties of gypseous soils to make these soils less sensitive to environmental conditions (Al-Obydi, 1992; Al-Zubaydi, 2007). The improvement of geotechnical properties of the gypseous soil using lime are chemical process, and take place in to two basic chemical reactions, short and long term reactions. In short term reaction cation exchange reaction, flocculation, aggregation and carbonation occur, these reactions leads to decrease the plasticity and increase the workability of the soil. The long term reactions is pozzolanic reaction, which responsible for strength gain and improve compressibility and volume change properties of the soil (Ingles and Metcalf, 1972; Little, 1995).

In this research the evaluation of the stability behavior of lime stabilized gypseous soil under different conditions were conducted. The study included three themes parts:

first was the effect of water velocity flow under different water temperature on the loss in weight and gypsum dissolution of soil samples was performed, second was investigated the effect of leaching on the permeability of the soil samples, and final the effect of soaking (static soaking) on the unconfined compressive strength, loss in weight and gypsum dissolution was examined.

MATERIALS AND TESTING PROGRAM

Soil and Lime

The soil used in this study was a gypseous soil having (20%) gypsum content, sampled in the locality of Al-Hader district about 80 Km from Mosul-Iraq. The liquid limit is equal to (46%) and its plasticity index to (24%). The specific gravity of the solid particles is equal to (2.58). The grain size distribution analysis of washed soil (soil without gypsum) referred to soil composition of (10%) sand, (40%) silt and (50%) clay. Based on the Atterberg limits values, the soil is classified as low plasticity clay (CL).

The lime used in this study is hydrated lime with (76%) activity, was obtained from Al- Meshrag Sculpture factory.

Samples preparation

A modified compaction effort (ASTM D-1557) was adopted in the preparation of soil samples. To prepare the soil samples, the oven – dried soil (2 days at 60^0 C) was first crushed and passed through sieve #4. The required amount of water corresponding to the optimum moisture content was added to the natural soil. All mixing was done manually. The mixture was then placed in plastic bags for mellowing time of 24 hour. For the stabilized soil, the soil samples were stabilized by 4% lime; representing the optimum lime content; based on the Illinois Procedure (Little, 1995). The soil – lime mixtures were prepared firstly, by general mixing of dry supposed quantities of soil-lime then the required amount of water would be added and mixed to get a uniform moisture distribution. The mixture was then placed in plastic bags and left for a period of time (1 hour) (Little, 1995). Then, the mixture was compacted in a specific mold of each types of the required testing. For the lime stabilized soil samples, the samples were immediately covered with aluminum film and coated with paraffin wax to reduce the moisture loss, then cured for 2 days at 49^0C.

Erosion Test

In order to study the stability behavior of lime stabilized gypseous soil, erosion test under water flow effect was carried out. During this test, the stabilized soil samples have been subjected to water flow under different water temperature values (25^0, 49^0 and 60^0 C), water flow velocity (0.05 m/sec – 1.2 m/sec) and flow duration (15, 30, 60,120 and 240 min.). In this test a hollow cylindrical samples (50 mm in diameter. and 100 mm height) was used. The hole was made along the length, with a diameter equal to (5 mm), with electrical drill. Device formed by (Al – Aarrajy, 2008), as shown in Figure (1) was used.

At the beginning, the sample was fixed in the cell, and the bases area of the sample (i.e. top and bottom) covered by adhesive impervious material such as silicon to

control the area of erosion. After that, the sample subjected to water flowing under different velocities (0.05, 0.1, 0.2, 0.4, 0.8, and 1.2 m / sec) and temperature (25^0, 49^0 and 60^0 C) for (15, 30, 60, 120 and 240 min.). At the end of the test, the sample was extracted from the cell and dried for (2 days) at (60^0 C) to obtain the dry weight and estimating the percent of loss in weight, then tested to find the residual gypsum content using chemical method which depend on the titration by EDTA (Ethylene Diamine Tetra Acetic).

Leaching Test

During the preparation of soil samples for leaching test, the soil samples were statically compacted using stainless steel mold with inside diameter of (97 mm) and a net height of (38.5 mm), at rate of 1 mm/min. The compaction mold with the soil sample in it was used as part of the leaching device as shown in Figure (2), in order to reduce the disturbance of the sample on extrusion from the mold. Constant head test was adopted to simulate the leaching process. The first step carrying out the leaching test was to saturate the sample in the mold. The water flow was applied from the bottom to the top of the soil samples in order to eliminate any air bubbles expected. After saturation the water was allowed to flow through the soil sample under hydraulic gradient of 8 for 60 days. The volume of water flow was recorded every 3 days for permeability calculations.

Soaking Test

In this approach, a cylindrical samples (50 mm dia. x 100 mm height) were immersed in glass container for (2, 7, 14, 28, 56 and 90) days. After the end of soaking period, the samples were tested to find the unconfined compressive strength. The tested sample was dried for two days to find the loss in gypsum content using chemical method which depend on the titration by EDTA. The dropped soil from sample surfaces in container bottom at each soaking period was collected to find the percent of loss in weight. The soaking water was changed continuously at a certain rate (3 days) to avoid the saturation of gypsum in the water.

RESULTS AND DISCUSSION

Effect of Flowing Water

Loss in Weight

The term loss in weight herein represents the loss in weight due to the gypsum dissolution and weight of eroded soil from the surfaces of the samples. Figures (3 and 4) and Table (1) show the effect of water velocity and time duration on the loss in weight of the lime stabilized soil samples. It is clear that, there is an increasing rate of weight losses with the increasing of flow speed and duration.

This behavior may due to increasing the erosion of the surfaces of the soil sample. Moreover, the eroded soil particles from the sample surface led to more gypsum dissolution by increasing the contact area between water and gypsum particles, resulting in formation of weak surfaces. The maximum values of the loss in weight for the higher water velocity (1.2 m/sec) and long flow duration (240 min.) were found to be between (8.0 – 27 %). The values of the weight loss of the stabilized soil samples

under different values of water temperature have been illustrated in Figure (5) and Table (1). An increasing in the loss in weight with increasing water temperature was observed. The percent of loss in weight for higher water velocity and long flow duration was increased from (8.0 % to 27 %) when water temperature increased from (25^0 C to 60^0 C). There is a sudden increase in weight loss at (49^0 C) compared with (25^0 C). This is probably due to the more chemical erosion (i.e. more cation exchange) between the water and treated soil. Therefore, the forces which tied these ions will weaken and this leads to accelerated in transition process of calcium (Ca^{++}) and sulfate (SO_4^{-2}) ions, and then mixed with water ions.

Loss in Gypsum Content

The losses in gypsum content increases with the water temperature increases. These increases were found to be (3.7, 4.5 and 5.3 %) for soil samples subjected to water temperature of (25^0,49^0 and 60^0 C) respectively, under (1.2 m/sec) water velocity for (240 min.).

Effect of Leaching on Permeability

Figure (6) shows the variation of permeability values on the long-term water circulation for the natural and 4% lime stabilized soil samples. The leaching test started after 2 days of curing at 49^0 C for the lime stabilized soil samples.

For the natural soil samples, the permeability value increased slightly up to 18 days of leaching and the value was ($7.1x10^{-7}$ cm/sec). There was a significant increasing in the permeability value and as the leaching time increased the permeability values increases to reach ($4.7x*10^{-6}$ cm/sec) at 51 days of leaching. After that, the permeability stabilized with ($4.9x10^{-6}$ cm/sec) at the end of leaching test. The increasing in the permeability values may be due to the changes in the texture and pores of soil samples during leaching process. Moreover, gypsum dissolution led to form cavities that accelerated the water flow through the soil sample.

Lime addition enhanced the permeability of stabilized soil samples. Continuous flow of water through the soil samples did not change the permeability value of soil. The maximum value was ($5.7x10^{-7}$ cm/sec) after 60 days of leaching. The reduction in permeability value with lime addition can be due to a reduction in interconnectivity of the pores by the pozzolanic reaction products.

Effect of Soaking

Figure (7) shows the effect of soaking on the unconfined compressive strength (q_u). A decrease in the unconfined compressive strength (q_u) was obtained for soaked samples, further decrease in strength was observed with increasing soaking period. The soaking periods gave decreasing ratios ranged between (5 to 52 %) of unsoaked samples. This behavior may be due to the uncompleted pozzolanic reaction, and/or more dissolution of gypsum that might occur by water change process which have been done every three days. Moreover, water intrusion led to the reduced cohesion between soil particles. After ending the unconfined compression test, the failed sample was tested to find the loss in gypsum content using chemical titration by EDTA (Ethylene Diamine Tetra Acetic) method. Results showed that the gypsum content in natural soil was decreased when lime was added to soil and cured for (2) days at (49^0

C). This percent decreased from (20 %) for natural soil to (17.5 %) for stabilized samples. This reduction may be due to some part of gypsum sharing in pozzolanic reaction (Hunter, 1988). Figure (8) shows the variation of gypsum content with soaking periods. The dissolved gypsum shows a gradual decrease with the soaking periods up to a certain period (i.e. 28 days), after that shows little changes.

Finally, the weight of dropped soil of lime stabilized soil samples was small. The maximum value of the dropped soil was occurred after long period of soaking)i.e. 90 days), this value reached to 1.67% of the total weight of soil sample.

CONCLUSIONS

From this study the following conclusion can be drawn:

1. Natural soil exhibits no strength resistance against erosion and soaking, and failed rapidly during soaking.
2. The flow water velocity, temperature and duration cause an increasing loss in weight.
3. High water velocity causes more loss in gypsum content, for all values of flow duration and water temperature.
4. Lime addition increases the stability of gypseous soil against erosion, soaking and leaching.

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Table (1) Percent loss in weight of lime stabilized soil samples.

Temp. (C^0)	Flow duration (min.)	Water Velocity (m/sec)					
		0.05	0.1	0.2	0.4	0.8	1.2
25^0	15	0.008	0.06	0.1	0.32	0.78	1.0
	30	0.21	0.31	0.54	0.86	1.13	1.85
	60	0.51	0.83	1.02	1.8	2.3	4
	120	0.81	1.1	1.73	2.11	3.8	6.5
	240	0.96	1.86	2.77	3.3	6.0	8.0
49^0	15	0.28	0.54	0.73	0.96	1.34	1.87
	30	0.81	0.97	1.23	1.88	2.65	3.3
	60	1.1	1.76	2.11	3.3	5.1	7.4
	120	1.74	2.87	4.1	6.8	9.2	11
	240	2.1	5.3	7.7	10.3	12.6	15
60^0	15	0.83	1.32	2.43	4.74	6.56	8.47
	30	1.89	2.85	4.32	7.13	9.66	12.77
	60	4.9	7.4	9.71	11.65	15.13	18.65
	120	8.74	10.41	13.63	17.12	19	22.87
	240	13.34	15.0	17.31	19.08	23.1	27.0

Figure (1) Testing device (A) and flow meter (B).

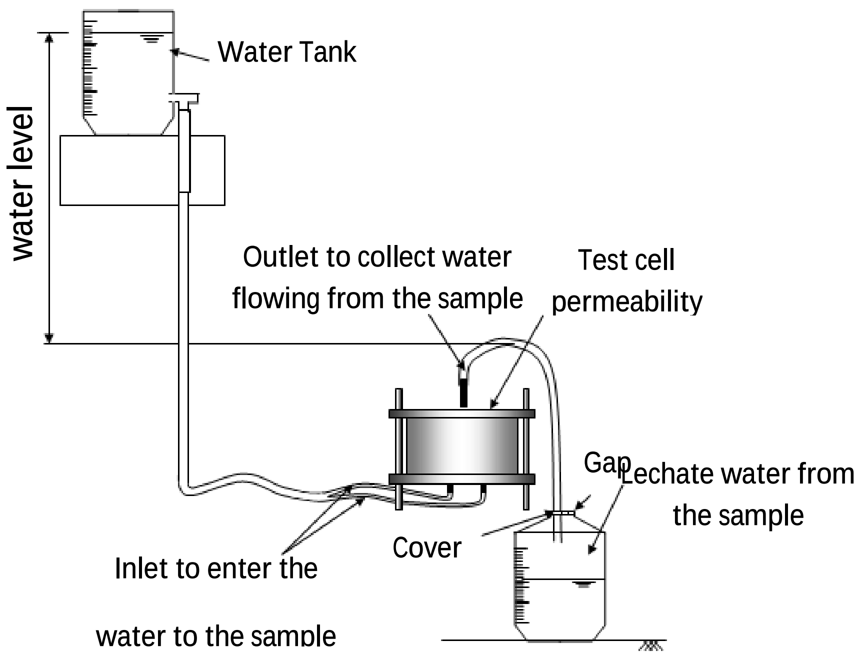


Figure (2) Leaching device.

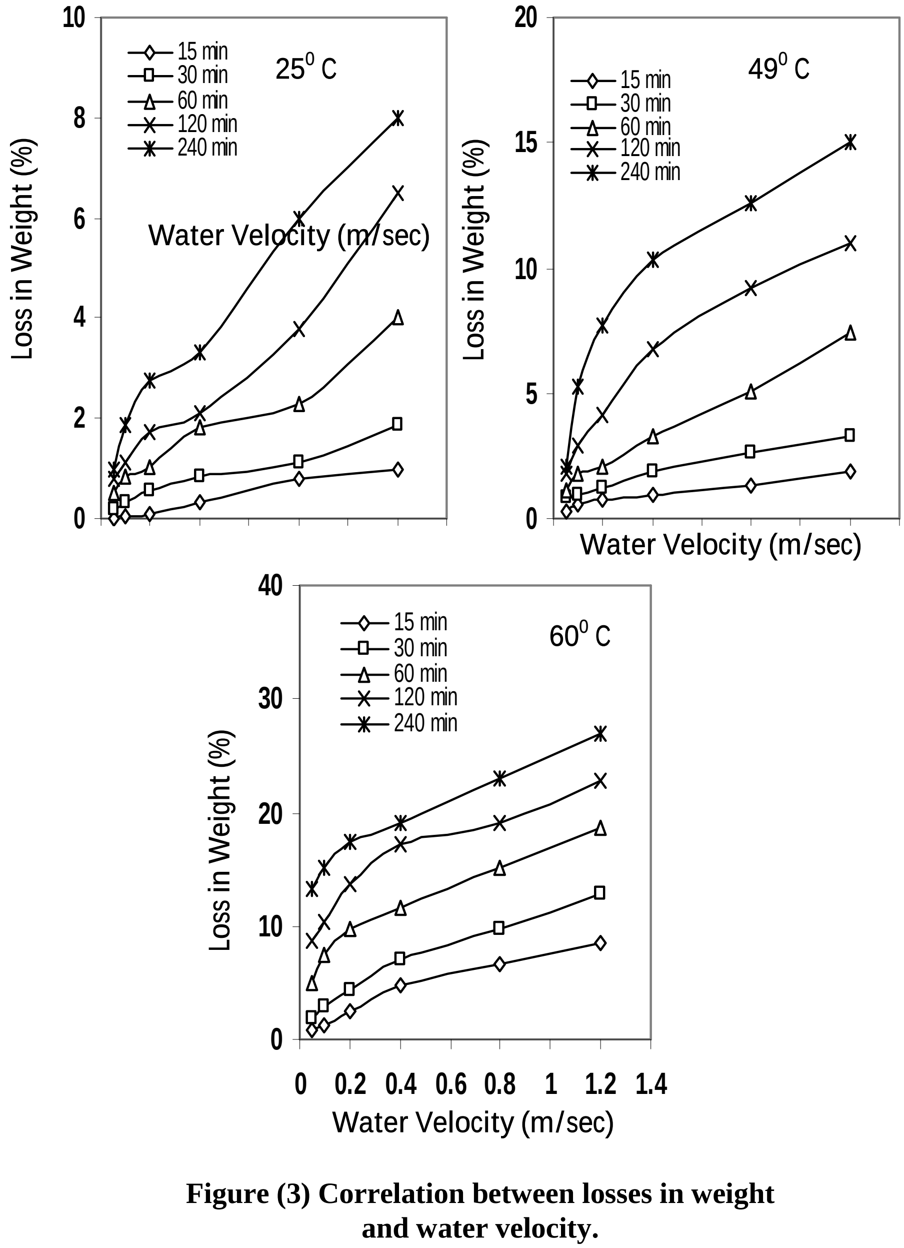


Figure (3) Correlation between losses in weight and water velocity.

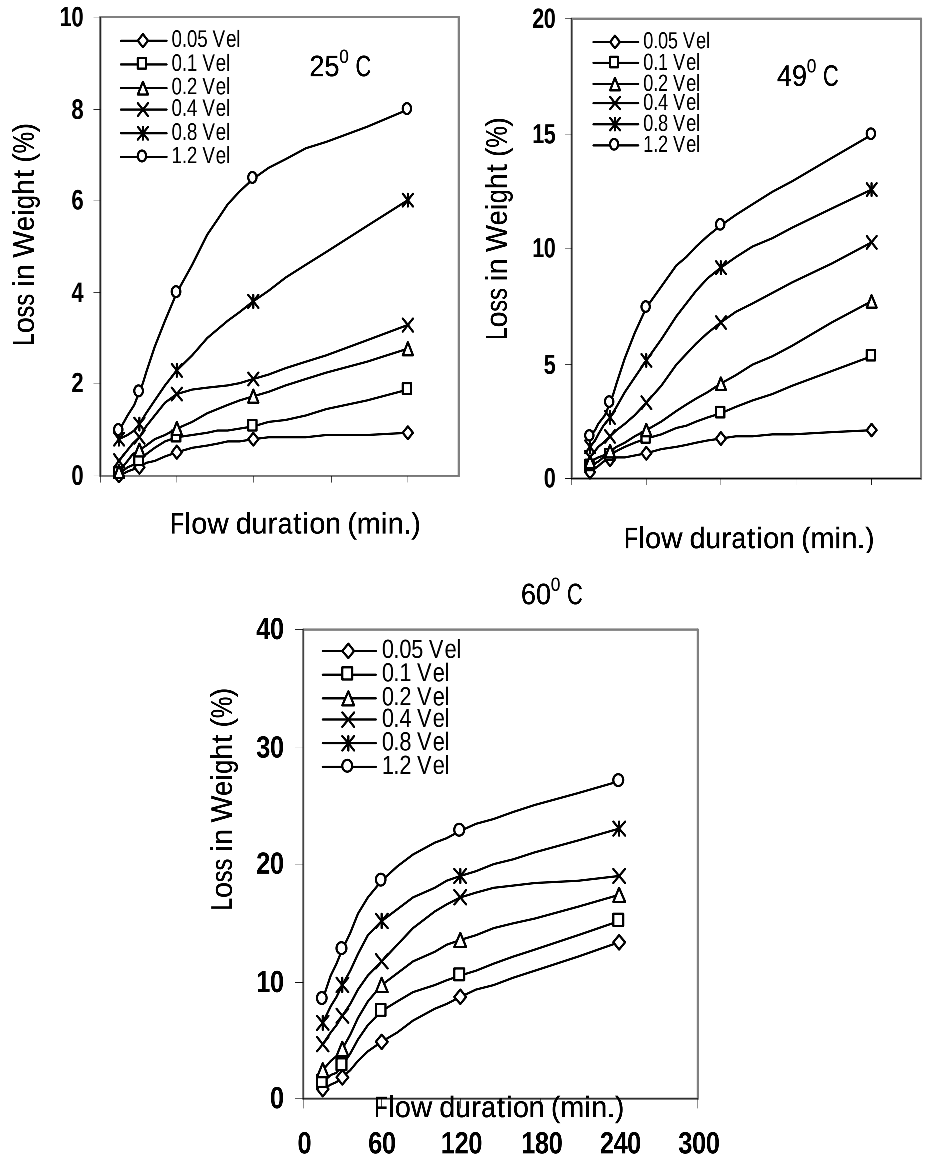
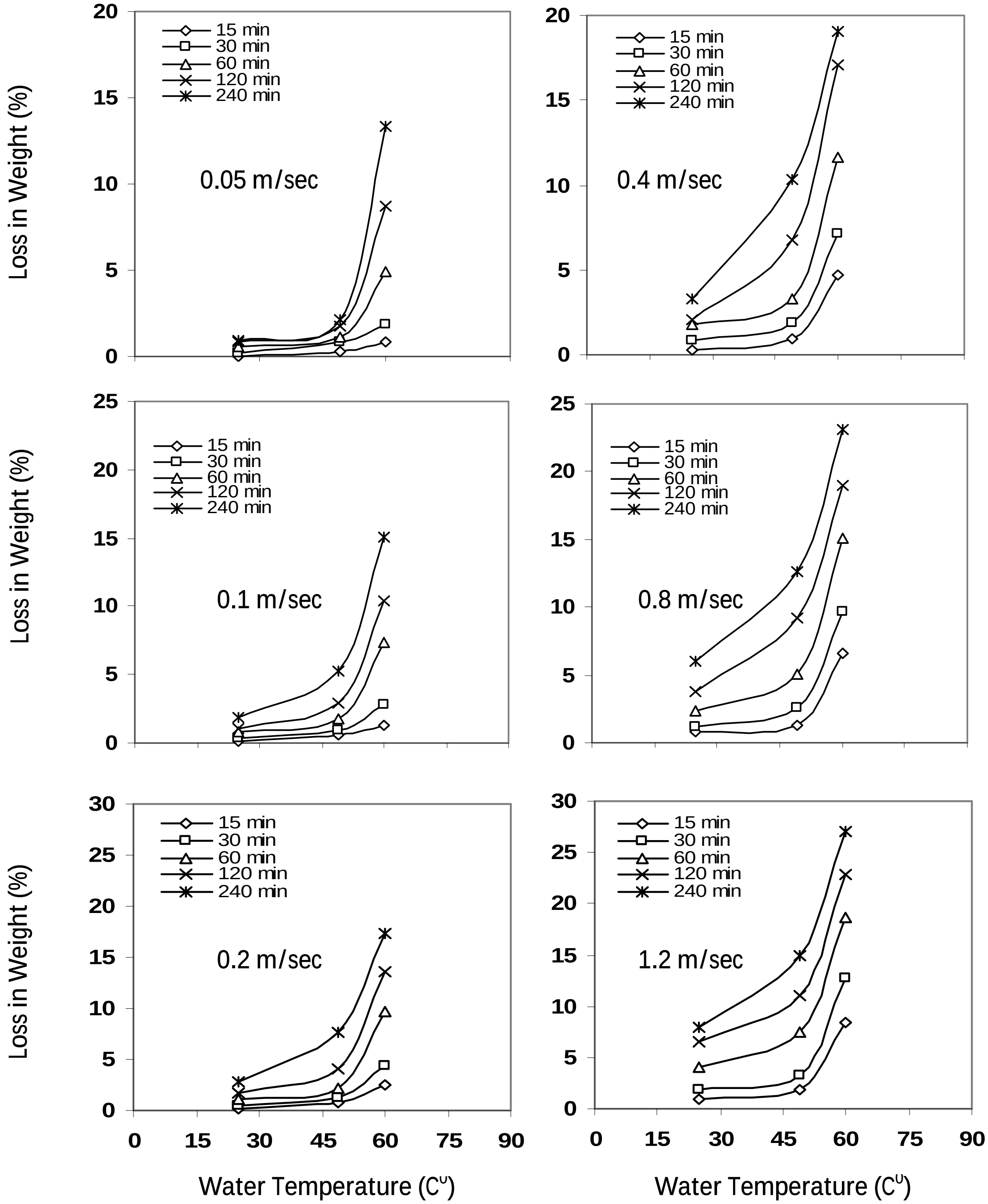


Figure (4) Correlation between losses in weight and flow duration.



Figure(5) Correlation between loss in weight and water temperature.

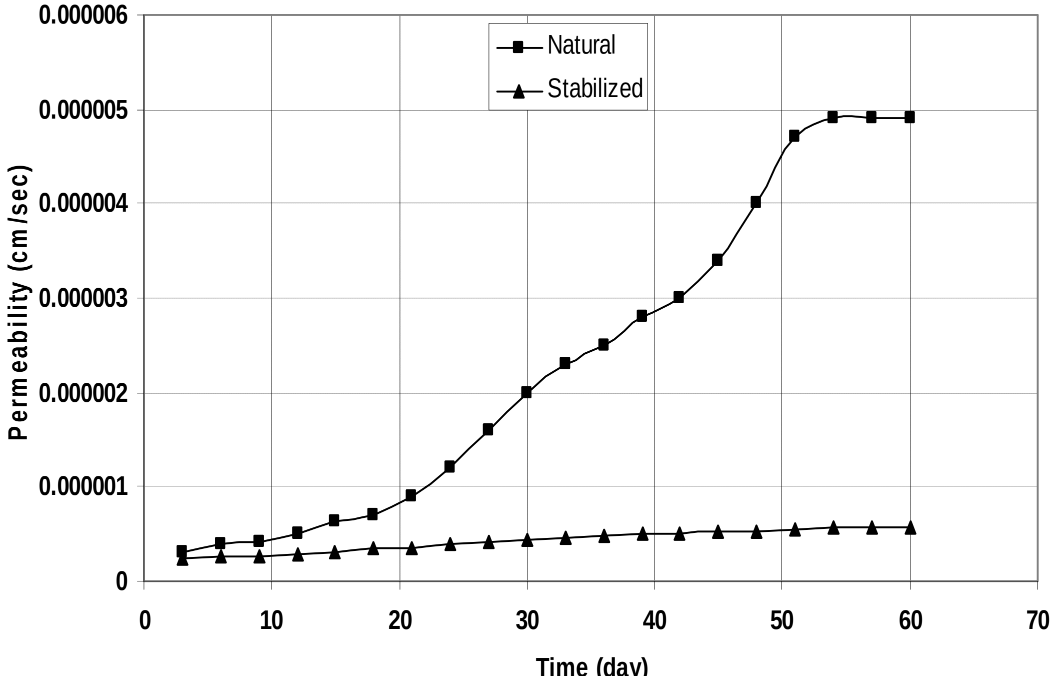


Figure (6) Variation of permeability values with time of leaching.

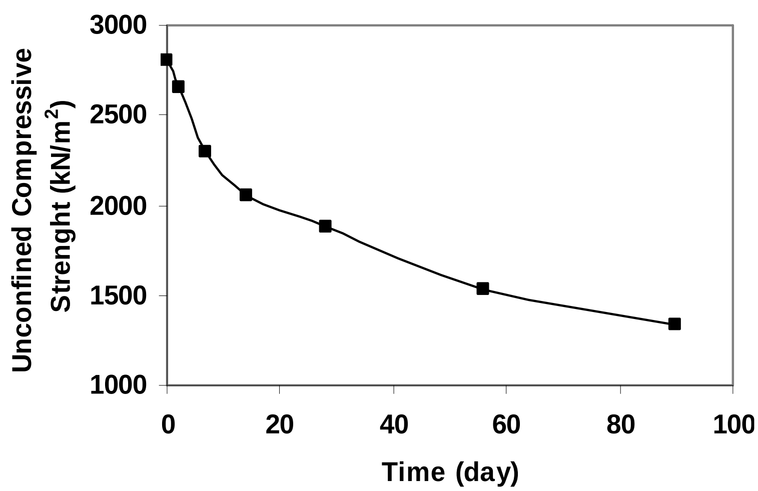


Figure (7) Variation of unconfined compressive strength Values with soaking time.

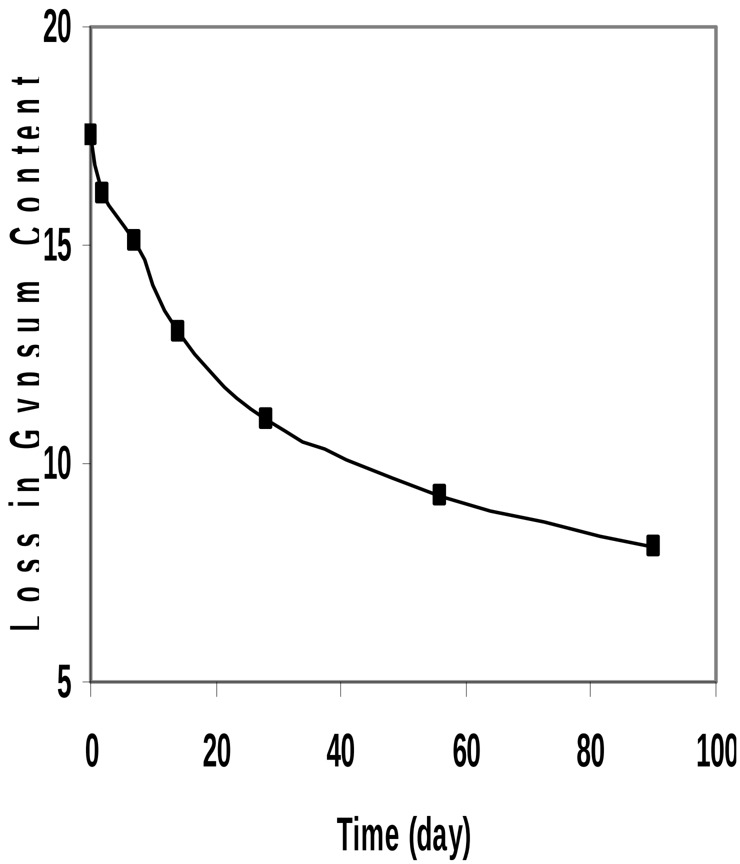


Figure (8) Variation of gypsum content with soaking time.