Improvement expansive soil properties (l.l, p.l, p.i) using ordinary Portland cement

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ABSTRACT:

The idea of this research is to improve the properties of expansive soil, such as, liquid limit, plastic limit and shrinkage limit by adding different amount of Ordinary Portland Cement to expansive soil. All variable which effect on soil properties, such as: amount of water, the ratio of compacting, time of mixing and the time for testing should be constant, to determine the differences in liquid limit, plastic limit and shrinkage limit for expansive soil with and without different amount of Ordinary Portland Cement. Four different percentages of Ordinary Portland Cement were used in those experiments, 2.5, 5.0, 10, and 15% by dry weight, these amounts were added to the expansive soil, mix each ratio with an amount of expansive soil and then samples were compacted by a steel rod. After that, the samples were cured for 7 days by covering them with a damp cloth. The samples were weighted and the dimension was measured on the first day; then on the seventh day; and finally on the 28th day to see the differences in weight and volume for each sample. The results were compared to find out which percentage indicated more effect on expansive durability in 7 and 28 days.

Liquid limit and plastic limit were reduced when the amount of cement is equal to 5%, and also the ratio of shrinkage, reduced when the amount of cement was equal to 5%. While the liquid limit, plastic limit and ratio of shrinkage seem to be constant when the amount of cement is more than 5%. So the ratio of 5% cement seems to be more suitable and more economical to use to improve the expansive soil properties.

Key Words: expansive soil properties, liquid limit, plastic limit, plasticity index, shrinkage situation.

تحسين خواص التربة الطينية الضعيفة (حد الليونة, حد المرونة) باستخدام السمنت البورتلاندي العادي

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1. INTRODUCTION:

Expansive soils are that type of soil which expand in volume when water content changes and it is found in many parts of the world; - America, Asia, Russia, the Middle East, and many other places. This kind of soil is found in these regions because they consistently have periods of rainfall and drought which causes significant soil instability, so they have repeating wet and dry cycling. Cracks and deformation are noticeable during construction **(Yucel et al. 2007).** This kind of soil has many problems related to the Civil or Geotechnical engineering especially with heavy construction or highways and roads. Expansive soil problems have appeared as cracking and destruction of highway embankments, pavements, railways, roadways, slab-on-grade members, building foundations, water lines and drain lines, canal and reservoir linings, and irrigation systems **(Gromko, 1974; Mowafy et al. 1985; Kehew, 1995).** The changing in soil volume called swelling and shrinkages, which is happened in soil whenever it is wet, because the water will fill all the voids between the soil particles. Hence, the particles will be spaced apart from each other and that leads to an increase in the soil volume **(Gulsah Yesilbas, 2004).** Expansive soil has the ability to swell and shrink when; affected by water volume, and this property has numerous effects on construction of basements and foundations causing significant problems to the constructions. The water content is coming from rain, flooding, groundwater and lakes; also this kind of soil is very common in agricultural areas, where there is a lot of plants there. The property which makes soil particles repeatedly expand when it is wet and shrink when it is dry, especially if the groundwater table is high-, is called fluctuation. Fluctuation causes many problems in civil engineering because the soil volume can change. The change in volume happens because of the water pressure and because of the small bond between clay minerals, and if it is not considered in design, the issue may in the future cause construction collapse. For expansive soil, which mostly contains small particles of clay and when the water fill the voids the clay mineral particles made are dispersed as layers which are tending to move away from each other because of thermal energy, resulting from a melting of clay particles in water **(Craig, 2004).**

Figure (1) describe the soil particle shape, the fine-grained particles are damage the stability when the soil is in a wet condition. **Figure (2)** explains the kind of clay minerals group; (a): montmorillonite, (b): illite and (c): kaolinite, which are crystalline hydrous aluminosilicates and those kinds have different behaviour when water is added to the soil.

Many studies have been done to see or discover how engineers can improve the soil's ability and increase the soil strength. Many additives have been added to the soil such as cement, fly ash fibres, polymers, and other materials to improve soil workability and increase both soil stabilisation and compressive and shear strength, then these additions are mixed with soil in depth (12- 18) inches. After that water is added to the soil mixture for 24-48 hours, and then the ground surface will be compacted to improve the soil strength and the soil durability (Western Stabilisation). The most common ways of achieving soil- stabilisation are:

• Use cement powder to stabilise the expansive soil, and to improve the mechanical properties of soils. Cement treatment was being used widely and positive effects of cement on the performance of soils have been recognised **(Balmer 1958; Mitchell 1976; Uddin et al. 1997; Lo and Wardani 2002).** Cement is a composite of oxides of calcium, silica, alumina and iron. This additive has the same results as lime stabilisation and it has many other useful properties such as very quick stabilisation and does not need mellowing time **(Farid et al., 2009).**

• Use lime-stabilisation - this is very commonly used and it is an economical choice. Lime is added to the clay soil as a presence of water and as a result optimum water content, shrinkage limit and soil strength are increased. While swelling potential liquid limit means that plasticity index and maximum dry density of soil is decreased **(Sherwood. 1993).**

• Fly ash stabilisation was used with expansive soil, and this additive has the same results as the lime or aggregate stabilisation **(Yucel et al. 2007).**

• Aggregate-soil stabilisation is by using aggregate, either natural aggregates or aggregates which are produced from crushed concrete or crushed asphalt, which result from construction demolition. Using aggregate or recycling demolished materials has many advantages, as it is more economical and it is more environmentally friendly **(Sherwood, 1995).**

• Add different materials for stabilisation, which contain Natural additives and could increase soil stability, such as; steel slug, particle board, drywall, gypsum, dimensional lumber, and plywood (special condition).

1.1 Soil- Cement Stabilisation

Soil stabilisation means any process which leads to change and improves the soil properties, so the engineers could use it in their construction without failure**, (Winterkorn, 1955).** Several methods are used to improve the properties of soils, such as; the stability, strength and load-bearing capacity, as well as durability. High strength and enhanced rigidity are achieved by reducing the void space between particles and preventing fluctuation; (swelling and shrinkage). Soil stabilisation by cement and lime are very commonly used, so the amount of cement which is used in soil stabilisation is affected by the durability requirement as well as depending also on the type of soil and the required properties, in general the range of cement content is from 3 to 16% by dry weight of soil, and whenever clay content increases the amount of cement increases too. Any type of cement could be used in soil stabilisation, but the most common type is Ordinary Portland Cement. Suitable soil stabilisation is determined by two factors, the first factor is satisfactory mixing between the soil and cement, the second factor is adequate hardening for the soil and cement mixture after mixing and compacting **(Bell, 1993).** When cement powder is added to the expansive soil particles, the mixture of fine particles of cement with water will fill most of the soil voids and is made into a mixture with electric discharge, which is both positively and negatively conducting; working to increase the bonding strength between soil molecules **(Craig, 2004).** However, when cement is added to clayey soils in the presence of water, a number of reactions happen leading to the change of soil properties such as cation exchange, carbonation, pozzolanic, and fluctuation **(Al-Rawas et al., 2005).** The cation exchang takes place between the cations associated with the surfaces of the electrically charged clay particles and the calcium cations of the cement. Clay particles become close to each other because of the effect of cation exchange and the attraction causes fluctuation. Fluctuation is primarily responsible for the change the engineering properties of clayey soils. While; cement stabilisation develops from the cementitious links between the calcium silicate and aluminate hydration products and the soil particles **(Croft, 1968; Al-Rawas et al., 2005).**

1.1.1 Types of Soil-Cement Stabilisation

All soil types could be stabilised with cement except the high plasticity soil or high organic soil, and the soil which has a particle size more than 20mm, because it would not have efficient surface finishing. Additionally, the finer particle size of less than 0.18mm should not be more than 50% soil and the soil with many different particle sizes is more suitable to mix with cement to achieve reasonably good economic results. Soil with 5-35% fines yield is often a more economical soil-cement mixture, if the soil particle size is more than the recommended ratio, the cement will cover the particle and they will be bound and pasted in their contact points (Bell, 1996).

1.1.2 Properties of Soil-Cement Stabilised

The properties of cement- stabilised soil are affected by two factors, first, is the amount of cement which is added. Second, is the volume of compacting. When the amount of cement increases, the bearing capacity and durability increases too. The soil tends to be stiffer because the ability to swell is reduced and it has a tendency towards shrinkage. The adequate compaction causes an increase in mixture density because the cement moisture fills the space between the clay minerals. The width of cracks in cement-soil after drying tends to be smaller and nearly closes the space in clay more than in cement-soil with sand. Also the compaction should be done in two hours of mixing soil-cement to avoid hardening of the mixture because of the cement hydration **(Bell, 1996).** There is an affect for sulphate content in soil on ordinary Portland cement, but in this study the affect were be summed to be neglected.

1.1.3 Soil-Cement Application

The soil-cement used in many types of construction, for example is used as a base under the pavement to avoid fine-grained pumping to the pavement surface, or it is used to protect the sloping in canals, coastal cliffs, dams, highways, or it is used when a massive full replacement is required to provide a rigid support to the foundations, or under the pile base **(Bell, 1993).** It is also used in temporary roads, parking, airport runways, and house foundations and in building block manufacture. Although the amount of cement which is added to the soil depends on the soil type and construction type **(Gillott, 1968).**

2. METHODOLOGY

This study is based on a laboratory experiment of expansive soil as shown in figure no. 3. Using a sample of expansive soil stored in the Geotechnical laboratory in Portsmouth University in the UK, with dry Ordinary Portland Cement that was added to dry expansive soil in the different percentage ratio of weight and then mixed with a constant water ratio to see the effect of cement on soil properties, such as, liquid limit, plastic limit and shrinkage limit, and then to analyse and compare between the percentages of cement.

2.1 Sample Preparation

Four different percentages of Ordinary Portland Cement were used in those experiments, 2.5, 5.0, 10, and 15% by dry weight, these amounts were added to the expansive soil, mix each ratio with- an amount of expansive soil and then samples were compacted by a steel rod. After that, the samples were cured for 7 days by covering them with a damp cloth. The samples were weighted and the dimension was measured on the first day; then on the seventh day; and finally on the 28th day to see the differences in weight and volume for each sample. The results were compared to find out which percentage indicated more effect on expansive durability in 7 and 28 days. In this study many types of lab experiment were undertaken to determine the changes in soil properties. The lab experiment consisted of :

- Experimenting to find out the liquid limit for soil.
- Experimenting to find out plastic limit for soil.

2.2 Soil Property Index

2.2.1 Liquid Limit

Liquid limit is defined as moisture content in the soil when it changes from a plastic to a viscous fluid **Figure 4** state which is expressed as a percentage of the weight of the oven dried soil, at the boundary between the liquid and plastic states of consistency. Subsequently, the liquid limit defined by British Standard 1377 -1990, is a water content corresponding to a cone penetration of 20 mm. According to British Standards all values of water content are expressed in a whole number if the value is above 10%.

2.2.2 Plastic Limit

The plastic limit is defined as the moisture content when the soil changes from a semi-solid to a plastic (flexible) state **Figure 5** which is expressed as a percentage of the weight of the oven-dry soil, at the boundary between the plastic state and semisolid states of consistency. It is the moisture content when the soil just begins to crumble and rolled into a thread ⅛ in. (3 mm) in diameter on a ground glass plate or other acceptable surface. According to British Standard 1377 -1990 all values of water content are expressed in a whole number if the value is above 10%.

3.2.3 Shrinkage Limit

After models were be done in process at section 2.1,all the dimensions were measured on the first day; then on the seventh day; and finally on the 28th day to see the relative shrinkage in volume. The samples were cured for the first 7 and 28 days by covering them with a damp cloth **Figures 6 and 7**.

3. RESULTS AND DISSECTION

As indicated by **Table 2**, the ratio of loss in soil weight and shrinkage in sample volume in 28 days for pure expansive soil is more than the ratio in 7 days. This occurs because of the samples drying during the experiment time. **Tables 3, 4, 5, and 6,** show the ratio of loss in soil weight and shrinkage in sample volume during 28 days is less than the ratio in 7 days, and that is because of the additives of cement which were added to the soil. The particles of cement absorb the water and reduce water evaporation, thus shrinkage is reduced. Cement treatment prevents volume changes because it produces a resistant layer that will protect the soil below from seasonable variations in moisture content (Portland Cement Association). Also, when cement adds to pure expansive soil the reaction between cement and soil reduces the amount of silt and clay size particles. The silt and clay size particles damaged the soil stability when the soil is in a moist or wet condition (Portland Cement Association).

Figure 8 shows the liquid limit decreases slightly between the pure soil point until it reaches a pure soil with 5% cement ratio, and then tends to be constant, while the plastic limit increases gradually for pure soil with 5% cement and then tends to become constant, while the plasticity index decreases gradually until it reaches a pure soil with 5% cement ratio, after which it increases very slightly until it reaches pure soil with a 15% cement ratio. **Figures 9, 10, 11, 12 and 13** show the results of liquid limit for pure soil with and without different amounts of soil, and the liquid limit is equal to the water content value at 200 of penetrometer reading. Thus, could be noticed the liquid limit decrease when the amount of cement increase **Table 1**, but the decline in the value of the liquid limit at least when the amount of cement exceeds 5% by dry wet.

4. CONCLUSION

As a result, it could be said that all amounts of Ordinary Portland Cement have an effect on the soil properties, such as liquid limit, plastic limit and plasticity index in different ratio. Also, the ratio of shrinkage has been affected by all the amounts of cement, but in different ratios. The amount of cement which is equal to 5% by dry weight when added to the expansive soil has more effect and reduces the ratio of shrinkage in the soil more than the other amounts, because the values of liquid limit, plastic limit and plasticity index seem to be constant when the ratio of cement is more than 5%. So, as a result of this research it could be said the 5% amount of cement by dry wet has more effect on shrinkage limit and it could be used to control or reduce the shrinkage in expansive soil.

5. REFERENCES

Al-Rawas, A.A., Hagoa, A.W. and Al-Sarmib, H. 2005. Effect of Lime, Cement and Sarooj (Artificial Pozzolan on the Swelling Potential of an Expansive Soil from Oman. *Building and Environment,* 40: 681-687.

Balmer, G. G. (1958). *Shear strength and elastic properties of soil-cement mixture under triaxial loading*, Portland Cement Association Research and Development Laboratories.

Bell F. G., (1993). Engineering Treatment of Soil. *Soil stabilisation*. E&FN Spon, Chapman& Hall, 2-6 Boundary Row, London SE1 8HN, UK.

Bell, F.G. 1996. Lime Stabilization of Clay Minerals and Soils, *Engineering Geology*; 42: 223-237.
Craig. R. F., 2004. Graig's Soil Mechanics 7th Edition. TJ International Ltd, Padstow, Cornwall. London.

Croft. J. B., 1968. The problem of predicting the suitability of soil for cementations stabilisation. *Engineering Geology*, 2, 397-424.

Farid Sariosseiri a, Balasingam Muhunthan Effect of cement treatment on Geotechnical properties of some Washington State soils. Engineering Geology 104 (2009) 119–125

Gillott, J. E., 1968.*Clay in engineering geology*. Elsevier Published Company, Amsterdam
Gromko, J.G., (1974), "*Expansive Soils*", Journal of the Geotechnical Engineering Deviator Vol. 100, pp. 666-687.

Gulsah Yesilbas, 2004. *Stabilisation of Expansive Soils using Aggregate, Waste, Rock Powder and Lime*. Retrieved Apr 5th, 2013 from: http://etd.lib.metu.edu.tr/upload/12604950/index.pdf.

Kehew, E.A., (1995), *Geology for Engineers and Environmental Scientists*, 2nd Ed. Prentice Hall Englewood Cliffs, New Jersey, pp. 295-3002.

Lo, S. R., and Wardani, S. P. R. (2002). *"Strength and dilatancy of a stabilised by a cement and fly ash mixture."* Canadian Geotechnical Journal, 39(1), 77-89.

Mitchell, J. K. (1976). "*The properties of Cement-stabilised soils*." Proceeding of Residential Workshop on Materials and Methods For Low Cost Road, Rail, and Reclamation Works, 365-404, Leura, Australia, Unisearch Ltd.

Mowafy, Y.M., Bauer, G.E., and Sakeb, F.H., (1985), "*Treatment of Expansive Soils: A laboratory Study*", Transportation Research Record 1032, pp. 34-39.

Portland Cement Association (2003). *Properties and Uses of Cement-Modified Soil*. Retrieved Aug 25th , 2013 from: http://www.recyclingroads.org/techdocs/IS411.PDF

Sherwood. P.1993. *Soil stabilization with cement and lime*. HMSO, London SW8 5DT

Sherwood. P. T. , 1995. *Alternative materials in road construction*. Thomas Telford Services Ltd, 1 Heron Quay, London E14 4JD

Uddin, K., Balasubramaniam, A. S., and Bergardo, D. T. (1997). "Engineering behaviors of cement-treated Bangkok soft clay." Geotechnical Engineering Journal, (28)1, 89-119.

Winterkorn, H. F. (1955). *The science of soil stabilization*. Bull. Highway Res. Board,108:1-24

Western Stabilization. Retrieved Apr 5th, 2013 from: https://www.google.com/webhp?client=aff-maxthon-newtab&channel=t2#hl=en&client=aff-maxthon-newtab&channel=t2&output=sear

Yucel Guneya, Dursun Sarib, Murat Cetinc, and Mustafa Tuncana. (2007). Impact of cyclic wetting–drying on swelling behavior of lime-stabilized soil. *Building and Environment* 42 (2007) 681–688

Table 1: Plasticity Index for samples

	Pure soil	Soil+2.5% cement	Soil+5% cement	Soil+10% cement	Soil+15% cement
Liquid limit	70	55	50	49	48
Plastic limit	32	38	38	37	35
Plasticity index	38	17	12	12	13

Table 2: Ratios of losing weight and reduction in length and diameter for pure soil

Samples no.	1 day			7 days			28 days		
	Weight	Length	Dia.	Weight	Length	Dia.	Weight	Length	Dia.
1	180.69	86.09	38.03	152.05	77.02	34.36	146.05	76.1	34.24
2	177.72	83.34	38.06	156.48	75.33	34.11	144.56	74.78	33.92
3	177.84	85.61	38.72	154.98	77.03	33.44	144.98	75.30	32.88
Ratio of losing %= 30%									

Table 3: Ratios of losing weight and reduction in length and diameter for pure soil + 2.5% cement

Samples no.	1 day			7 days			28 days		
	Weight	Length	Dia.	Weight	Length	Dia.	Weight	Length	Dia.
1	181.70	84.69	38.89	173.75	82.65	37.43	170.10	81.22	38.19
2	184.41	85.59	38.72	179.24	83.81	38.39	171.80	83.20	38.13
3	181.29	84.93	38.50	177.39	83.22	38.14	171.56	82.87	38.10
Ratio of volume losing %= 7%									

Table 4: Ratios of losing weight and reduction in length and diameter for poor soil + 5% cement

Samples no.	1 day			7 days			28 days		
	Weight	Length	Dia.	Weight	Length	Dia.	Weight	Length	Dia.
1	182.30	85.16	38.55	173.78	84.81	38.43	173.57	84.38	38.16
2	181.57	85.07	38.55	174.23	84.81	38.32	173.77	84.08	38.20
3	183.86	86.34	38.50	176.29	85.78	38.04	175.54	85.06	37.92
Ratio of volume losing % = 3%									

Table 5: Ratios of losing weight and reduction in length and diameter for pure soil + 10% cement

Samples no.	1 day			7 days			28 days		
	Weight	Length	Dia.	Weight	Length	Dia.	Weight	Length	Dia.
1	182.40	87.32	38.75	175.47	85.96	38.37	175.23	85.88	38.32
2	182.79	86.02	38.30	176.38	85.29	38.18	175.02	85.16	38.13
3	181.54	85.90	38.87	174.30	85.26	38.28	174.10	85.17	38.24
Ratio of volume losing %= 5%									

Table 6: Ratios of losing weight and reduction in length and diameter for pure soil + 15% cement

Samples no.	1 day			7 days			28 days		
	Weight	Length	Dia.	Weight	Length	Dia.	Weight	Length	Dia.
1	187.81	85.90	38.66	180.67	84.65	38.40	180.23	84.54	38.20
2	186.47	85.87	38.76	180.56	84.81	38.38	180.27	84.65	38.30
3	186.07	85.45	38.82	180.45	84.22	38.22	181.03	84.03	38.10
Ratio of volume losing %= 4%									

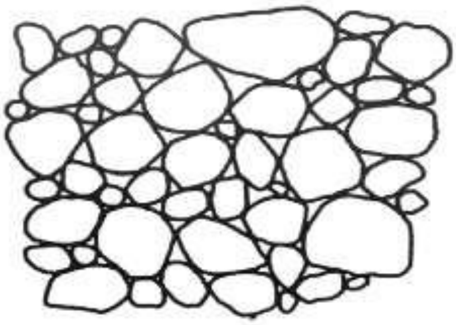

Figure (1): Soil particle shape (Craig, 2004

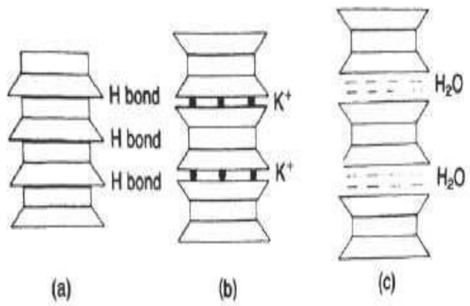

Figure (2): Soil layers when water is added (Craig, 2004).

Figure (3): Mixing soil with cement

Figure (4): Penetrometer and equipment for liquid limit experiment.

Figure (5): Plastic limit experiment

Figure (6): Samples covered with wet cloth

Figure (7): Sample weighted and dimensions taken

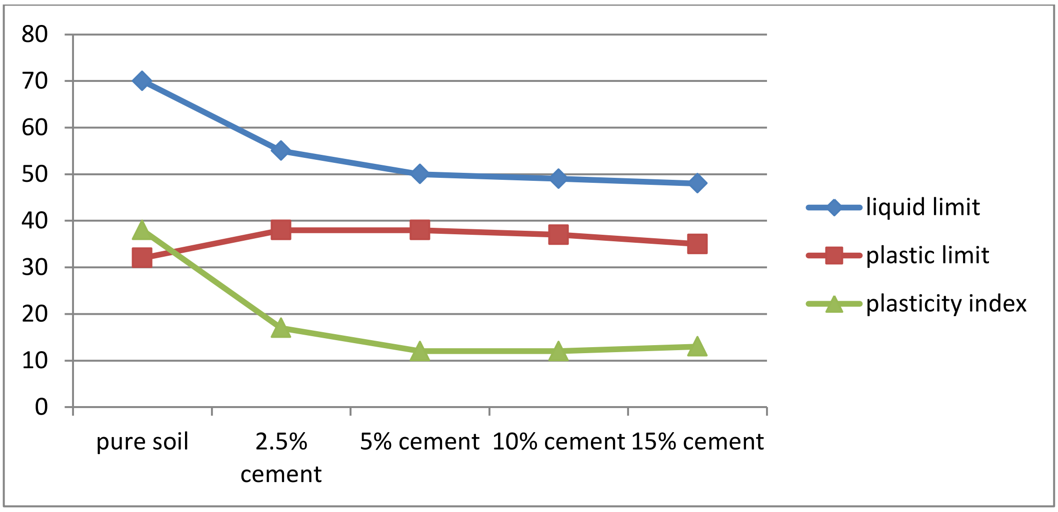

Figure (8): Liquid, plastic limit and plasticity index for expansive soil with different amount of cement.

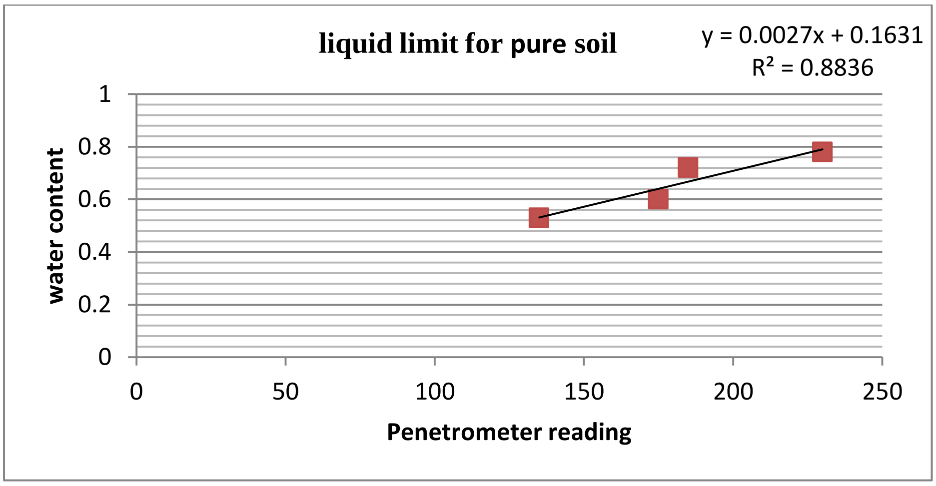

Figure (9): Water content of pure soil

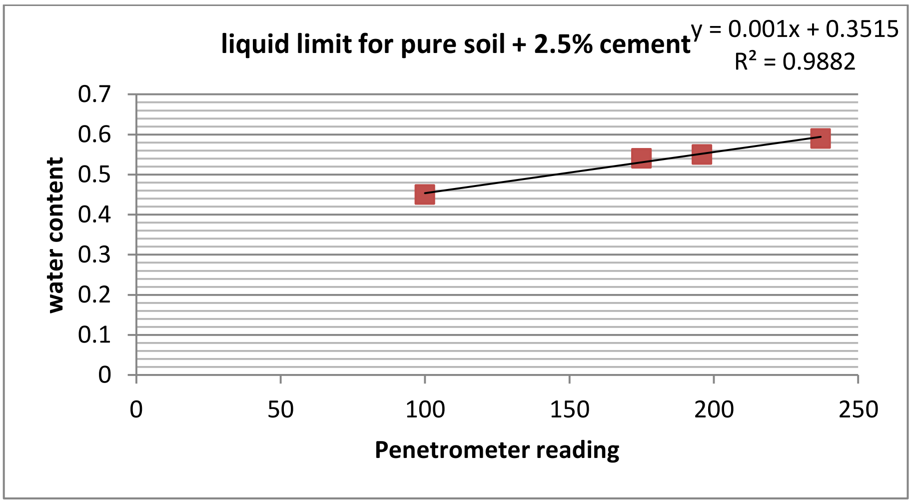

Figure (10): Water content of pure soil + 2.5% cement

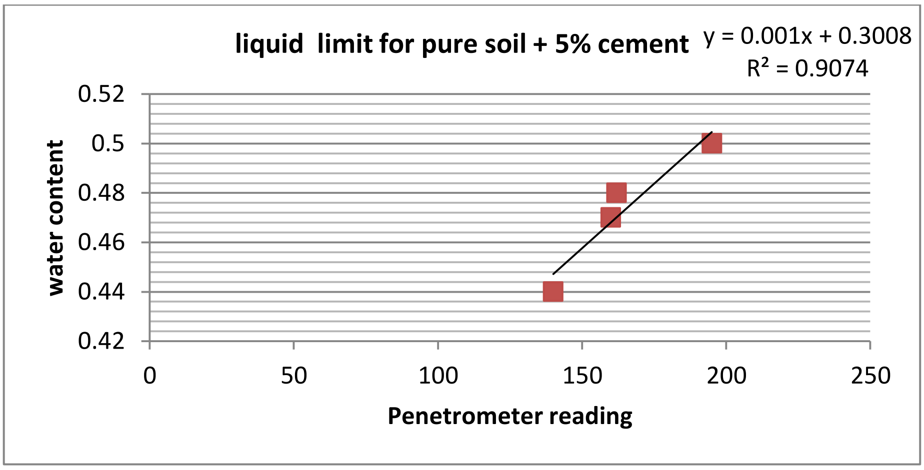

Figure (11): Water content of pure soil + 5% cement

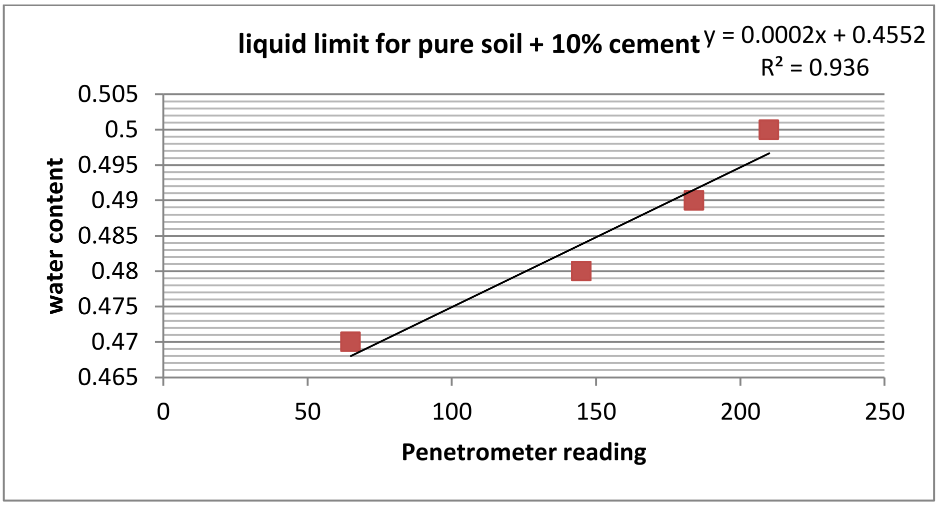

Figure (12): Water content of pure soil + 10% cement

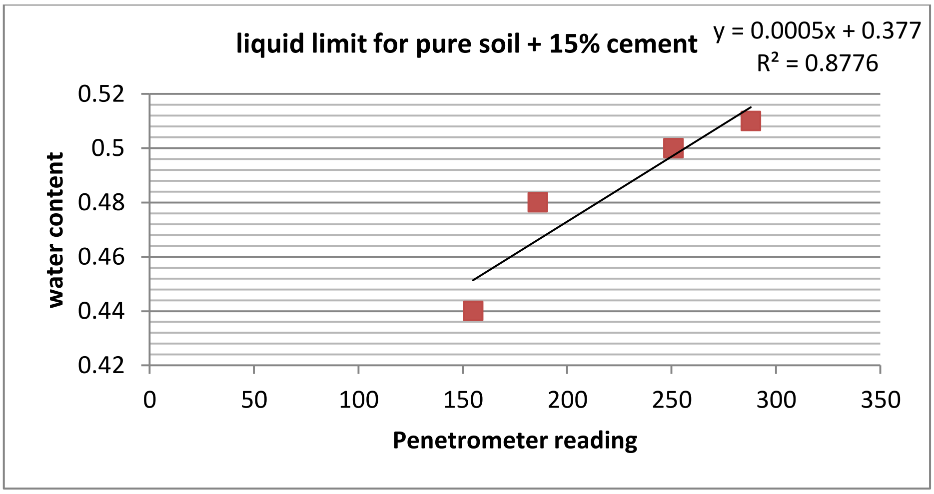

Figure (13): Water content of pure soil + 15% cement