ISSN: 2581-3404 (Online)
International Journal of Innovative Research in Technology and Management, Vol-5, Issue-3, 2021.

Use of Polyethylene and Cement Materials For Strengthening of Soil

Prantik Sen[1], Dr. Pradeep kumar T.V.

[1]PG, Research Scholar, Department of Civil Engineering

[2] Professor, Department of Civil Engineering

[1,2]IES Institute of Technology and Management, Bhopal, (M.P.), India

Abstract- *The aim of this dissertation is to determine unconfined compressive strength value and CBR value of soils when they are stabilized using cement and polymer. Soil stabilization has been widely used as an alternate to substitute the shortage of suitable material on site. The utilization of non-traditional compound stabilizers in soil improvement is developing every day. In this investigation a lab try was led to assess the impacts of waterborne polymer on unconfined pressure quality on sandy soil and CBR Test on clayey soil .The lab tests were performed including grain size of sandy soil, unit weight, and unconfined compressive quality test. The sand and different measures of polymer (2%, 3%, and 4%) and concrete (20%, 30%, and 40%) were blended in with every one of them into mixture utilizing hand blending in research centre conditions. The examples were exposed to unconfined pressure tests to decide their quality following 7 days of restoring. The consequences of the tests showed that the waterborne polymer fundamentally improved the unconfined pressure quality of sandy soils which have weakness of liquefaction. Polymer altered the building properties of soil through physical holding. The amount of polymer required to switch the engineering properties was directly associated with specific surface and soil particle coating thickness. The soils amended using polymer is less strengthening compared to soils amended using cement.*

Keyword: *Soil Stabilization; Unconfined compressive strength; CBR test; Polymer; etc.*

Introduction

1.1 General

Soil stabilization may be a regulated process to enhance the soil by using additives so as to use it as base or sub base courses and carry the expected traffic and pavement loads. There are several methods by which soils are often stabilized.

There are two methods to reinforce the properties of sandy soils; one among them is that the mechanical stabilization which is mixed the natural soil and stabilizing material together for obtaining a homogeneous mixture and therefore the other is adding stabilizing material into un-disturbed soils to get interaction by letting it permeate through soil voids. In chemical stabilization, the properties of locally available soil is modified in order to improve its strengthen characteristics. The two most ordinarily used chemical stabilization methods are lime stabilization and cement stabilization.

In the past, the quality nature of the subgrade soil utilized in asphalt development had been dictated by different lab tests, for example, the California bearing proportion (CBR), Hveem stabilometer and cohesiometer test (The Hveem technique), and R-esteem tests so as to describe the asphalt materials. In any case, neither of these techniques considers the impact of cyclic stacking of the vehicular burden on the asphalt because of static nature of their stacking conditions.

The ongoing improvement in asphalt configuration incorporates the presentation of solidness based modulus, called the tough modulus, which manages the continued stacking condition on the materials to be tried, along these lines recreating the genuine vehicular stacking in the field. The continued stacking triaxial test is performed inside the flexible scope of the dirt so as to decide the versatile modulus. Then again, the perpetual distortion manages the cyclic stacking of materials past as far as possible or once in a while up to disappointment of the examples so as to assess the rutting execution (single- stage tests) and diverse investigation stages (or cut-off points) of the materials (multi-stage tests). Notwithstanding the more exact results from strong modulus and lasting distortion tests, a few creators contractual workers despite everything lean toward utilizing CBR esteem or some other traditional technique in the plan of asphalt as opposed to the utilization of versatile modulus because of related ease and lesser time contrasted with the continued stacking triaxial tests.

1.2 Objectives

• To study adverse affect of increase in moisture content in soil and the respective strength characteristics. Soil possesses excellent performance at the optimum moisture content or below the optimum moisture content (dry side of optimum); however the strength and stiffness of soils reduces drastically as the moisture content increases beyond the optimum (wet side of optimum).

• To study shrinking or swelling properties of soils due to presence of high water level. The shrink/swell characteristic of the soils is a function of in situ moisture content.

• To study the stabilization process of soils when polymer and cement are mixed in them.

• To compare the different types of stabilization processes according to the soil type. Due to soft nature of soil in some regions and with the presence of high water level strength/stiffness of subgrade soil is just too weak to support the pavement loads. In order to cope with this problem, various techniques have been applied by engineers depending upon the types of the soil. For example, mechanical stabilization is preferred to coarse grained soils. But, in some regions, with soft clay subgrade and high water level, it's customary to treat the soils with some chemical stabilizers or calcium rich stabilizers.

• To predict the behavior of the subgrade soil at optimum moisture content. Most of the soils have in situ moisture content higher than the optimum, and therefore the prediction of subgrade behavior based only on the property around the optimum or near the optimum on either side is not enough. The use of various stabilizers supported the properties of the raw to treated/stabilized subgrade soil has made it easier to construct pavement on high moisture contents and weak soil subgrade.

II. Literature Review

2.1 General

Extensive research has been finished relating to the utilization of customary stabilizers, in particular lime and concrete. The adjustment instruments for lime and concrete are very much archived, and the adequacy of these conventional stabilizers has been exhibited in numerous applications. Nonetheless, moderately little examination reporting the utilization of non-traditional stabilizers, for example, manufactured polymers and magnesium chloride is accessible, and their presentation record is changed.

Sharifah Zaliha, H. Kamarudin and A.M. Mustafa Al Bakri (2010), looking for the best soil stabilizers to beat issues happen by the delicate soils are as yet being the primary concern, not exclusively to accomplish the necessary soil designing properties yet additionally by thinking about the expense and the impact to the earth. The target of this paper was to survey the methods that had been accomplished for soil adjustment dependent on exploratory examinations. Examination on different materials had been done so as to assess their viability as soil stabilizer, which included the utilization of sodium hydroxide added substance, fly debris geo-polymeric folio, different remains and cementitious binders. These materials were talked about in this paper and their adequacy for balancing out delicate soils were seen from the got results, only in term of solidarity, based on unconfined compressive quality (UCS) test and California Bearing Ratio (CBR) test that had been directed. The quality of delicate soils was fundamentally expanded with the utilized of these materials and assumed they had the potential as compelling soil stabilizers in field application.

Yıldız et al., (2012) analyzed slight areas of solidified sediment residue and dirt and discovered flat ice focal points opposite to the heading of freezing, and vertical ice-filled shrinkage splits that were connected to shape segments with polygonal cross segments. Othman and Benson explored the impact of compaction conditions (shaping water content and compactive exertion) and outside conditions (temperature slope, extreme temperature, dimensionality of freezing, number of freeze-defrost cycles and condition of weight) on the pressure driven conductivity of three compacted dirts of various properties. Research facility considers demonstrate that the quantity of freeze-defrost cycles, paces of freezing and conditions of pressure have the biggest impact on the change in water driven conductivity. The water driven conductivity increments as the pace of freezing and number of freeze-defrost cycles are expanded and as the overburden pressure is diminished. Different variables, for example, a definitive temperature, dimensionality of freezing, and accessibility of an outer gracefully of water, don't seem to have a noteworthy impact.

Mohammed Thafer and Ali Fırat (2014), any metropolitan zones are presently battling with the high volume of strong squanders, particularly the development and destruction materials. In this examination, the squashed waste cement (CWC), which is viewed as perhaps the greatest segment of strong waste, was utilized to improve some geotechnical properties of natural soil. The CWC at the proportions of 5%, 10%, 15%, and 20% were added to natural soil so as to direct an escalated arrangement of test tests. The lab tests incorporated as far as possible by fall cone, adjusted compaction, unconfined compressive quality (UCS), and growing rate. The outcomes show that when the CWC rates were expanded to half, there were diminishes of about 30% and 60% in fluid breaking point and pliancy record of dirt, individually. An expansion of about 35% in γdrymax for the natural soil was seen when the CWC content was expanded from 10% to half. A decrease of about half of wopt for natural soil was appeared by expanding the CWC rate to half. The UCS estimations of the natural residue increment by around 25% by expanding the CWC rate up to half. The expanding rate expanded by adding CWC up to 30%, and afterward diminished with the option of CWC up to half.

Qiang Tang,Yang Liu and Fan Gu (2016), this examination explored the hardening/adjustment of fly debris containing hefty metals utilizing the Portland concrete as a cover. It is discovered that both the concrete/fly debris proportion and restoring time effectively affect the mechanical (i.e., compressive quality) and draining practices of the settled fly debris blends. At the point when the concrete/fly debris proportion increments from 4 : 6 to 8 : 2, the expansion of compressive quality proportion raises from 42.24% to 80.36%; then, the draining measure of weighty metals diminishes by 2.33% to 85.23%. At the point when the restoring time increments from 3 days to 56 days, the compressive quality proportion of blends raises from 240.00% to 414.29%; in the interim, the draining measure of weighty metals diminishes by 16.49% to 88.70%. The lessening of compressive quality with the lower concrete/fly debris proportions and less restoring time can be credited to the expansion of fly debris stacking, which obstructs the development of ettringite and demolishes the structure of hydration items, along these lines coming about in the pozzolanic response and obsession of water atoms. Besides, the presence of concrete causes the lessening of draining, which results from the arrangement of ettringite and the limitation of hefty metal particle movement in numerous structures, for example, C-S-H gel and adsorption.

Mohammed N J Alzaidy (2019), using of concoction admixtures, for example, lime, concrete, bitumen and so forth in soil adjustment is profoundly costly. In this manner, it is desirable over supplant these produced materials by different sorts of soil added substances to lessen the expense. This examination researches an exploratory investigation for settling a clayey soil with eggshell powder as a substitution of business lime and plastic squanders strips so as to decrease the fragility of soil balanced out by eggshell powder, and its impact in the designing properties of the dirt. Three different extents of eggshell powder (2%, 5% and 8% by weight of dry soil) and plastic squanders strips (0.25%, 0.5% and 1% by weight of dry soil) have been utilized to make nine gatherings of settled soil tests to acquire the ideal level of every added substance. The examination was finished by leading compaction, unconfined pressure, expanding potential, direct shear and California bearing proportion tests. It was seen that eggshell powder, plastic waste fiber substance and restoring length had huge impact in the building properties of the balanced out soil. The outcomes demonstrated that the unconfined pressure quality, California bearing proportion esteems and shear quality boundaries had expanded with increment in eggshell powder content up as far as possible, from there on it will somewhat diminish, while an expansion in eggshell powder prompted a decrease of growing potential. Then again, an expansion in plastic squanders fiber content prompted an expansion in the quality properties referenced and decreases of expanding potential. In addition, it is seen that restoring span had altogether improved the quality properties referenced of the balanced out soil tests.

2.2 Significance of Polymers

1. Polypropylene (PP) fiber: It is the most broadly utilized incorporation in the lab testing of soil adjustment. At present, PP filaments are utilized to improve the dirt quality properties, to lessen the shrinkage properties and to beat concoction and organic corruption. PP fiber fortification likewise improves the unconfined compressive quality (UCS) of the dirt and decreased both volumetric shrinkage strains and swell weights of the broad mud.

From the analyses on field test segments in which a sandy soil was settled with PP filaments, it was reasoned that the procedure demonstrated incredible potential for military runway and street applications and that a 203-mm thick sand fiber layer was adequate to help significant measures of military truck traffic. Field explores likewise demonstrated that it was important to fix the surface utilizing emulsion folio to forestall fiber pullout under traffic.

Maheshwari blended polyester strands of 12 mm long with exceptionally compressible clayey soil change from 0% to 1%. The outcomes showed that fortification of profoundlycompressible clayey soil with arbitrarily disseminated filaments caused an expansion in a definitive bearing limit and lessening in settlement at a definitive burden. They presumed that the dirt bearing limit and the sheltered bearing weight (SBP) both increment with increment in fiber content up to 0.50% and afterward it diminishes with further incorporation of strands.

2. Polyethylene (PE) filaments: The possibility of fortifying soil with polyethylene (PE) strips and additionally strands has been likewise explored partly. It has been accounted for that the presence of a little part of high thickness PE (HDPE) filaments can expand the break vitality of the dirt. These days, GEOFIBERS ordinarily 1–2 in long discrete PP as well as PE fibrillated or tape strands, are blended or mixed into sand or earth soils. Yet, realize that a few analysts have applied the term "Geofiber" for PP filaments utilized in soil support.

Sobhan and Mashand showed the significance of utilizing strength as a proportion of execution. These investigations indicated that increments in rigidity with included HDPE strips were not understood yet huge increments in sturdiness coming about because of expanded strain limit was watched. With expanding sturdiness, a great part of the normal presentation benefits because of fiber incorporation are in the post-top burden bit of the pressure strain conduct. Hence, as the filaments create pressure, an improved pressure strain reaction is the outcome. In any case, enhancements in weariness conduct were not noted.

3. Glass strands: Consoli et al. demonstrated that consideration of glass strands in silty sand adequately improves top quality. In another work, Consoli et al. inspected the impact of PP, PET and glass filaments on the mechanical conduct of fiber-fortified solidified soils. Their outcomes demonstrated that the consideration of PP fiber essentially improved the fragile conduct of solidified soils, though the deviatoric worries at disappointment somewhat diminished. Dissimilar to the instance of PP fiber, the consideration of PET and glass strands marginally expanded the deviatoric worries at disappointment and somewhat decreased the fragility. Maher and Ho considered the conduct of kaolinite–fiber (PP and glass filaments) composites, and found that the expansion in the UCS was more articulated in the glass fiber-fortified examples.

4. Nylon fiber: Kumar and Tabor contemplated the quality conduct of nylon fiber strengthened silty earth with various level of compaction. The examination shows that pinnacle and leftover quality of the examples for 93% compaction are essentially more than the examples compacted at the higher densities.

III. Experimental and Investigations

3.1 Methodology

In this dissertation, cement and Polymer is used for soil stabilization. Cement and Polymer content is varied in two sorts of soil viz. Sandy and Clayey Soil. The effect of unconfined compression strength and CBR values are studied in the Experiment with the variation in contents of cement and Polymer. Firstly mechanical analysis of two types of soil is done, then the soil is mixed with different contents of cement and polymer and their variation are studied.

3.2 Material Used

1) Sandy Soil

Table 1- Engineering properties of sandy soil

Property	Sample
Specific gravity	2.75
Grain size:	
(4.75-20) mm (%)	2.5
(< 4.75mm) (%)	97.5
Max. void ratio (emax)	0.8
Min. void ratio (emin)	0.42
Void ratio, (%)	1.024
Optimum moisture content (%)	15
Maximum dry unit weight (g/cm^3)	1.86
Soil classification (USCS)	S

2) Clay Soil

Table 2- Index properties

Description of Index properties	Experimental Value
Liquid limit	30%
Plastic limit	18.50%
Plastic Index	11.50%
Shrinkage limit	14.65%

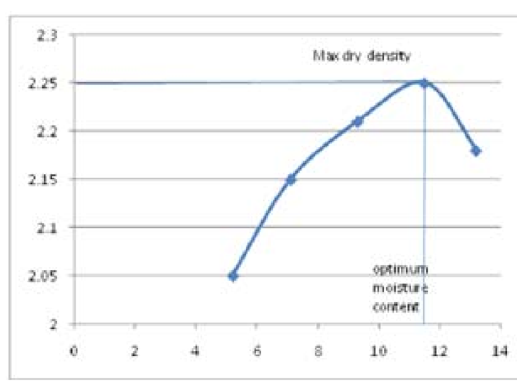

Figure 1. Result of modified proctor compaction

3) Cement

Table 3- Properties of Cement

Properties of 43 Grade OPC								
Fineness (sq.m/kg) min	Soundness (mm) Max	Setting time		Compressive strength				
		Initial mts)min	Final (mts) Max	ay M pa	3 day Mpa	7 day Mpa	28 day Mpa
225	10	30	600	NS	23	23	43

4) Polymers

Table 4- Important physicochemical properties of as-received emulsion

Name	**Acrylic-Copolymer watered solution**
Physical state	Liquid-white colour
Solvability in water	Solution
Boiling point	100°
Water Absorption	1% max
Non-self-burning	Non-explosive
Applicable temperature	Not less than 10°
Density (g/cm^3)	1.11 (20°)
Toxicity	Non Toxic

3.3 Tests Conducted

1) CALIFORNIA BEARING RATIO TESTING

The CBR is that the only test which may find out the strength of a subgrade. By this test we will compare the strength of various subgrade materials .The CBR test is completed during a standard manner by which one can determine or design the strength or thickness of subgrade layer. CBR value is inversely proportional to thickness of the pavement layer. If the subgrade is stronger, the upper is that the CBR value, so lesser thickness is required and vice-versa.

The California bearing proportion, CBR is communicated as the proportion of the heap opposition (test heap) of a given soil test to the standard burden at 2.5mm or 5mm entrance, communicated in rate;

CBR = (Test load/Standard load) ×100

The standard load for two .5mm and 5mm penetrations are 1370 kg and 2055 kg respectively. The CBR test is carried out on a small scale penetration of dial reading with probing ring divisions. Initially experiments were conducted to seek out different properties of soil like index properties, grain size distribution etc. Later on heavy compaction tests were conducted to find out the optimum moisture content & corresponding maximum dry density.

Then CBR tests were made at OMC and analysis made to investigate the variation of CBR with respect to different days of soaking, i.e. from unsoaked (day 0) to soaked (day 4). Using the moisture content and corresponding dry density the amount of soil used for CBR was calculated. The sample was tested using the CBR instruments and each soil sample was soaked for 1 day, 2 day, 3 day, 4 day, and corresponding CBR values was found out.

All CBR samples are prepared by first measuring the required amount of soil to fill a typical CBR mould into a 4 kg bag. The amount of water required to get the soil to optimum moisture content is mixed and homogenously distributed. Some chemical additives are also mixed at the desired content to the moist the soil mixture. The chemical added is then blended with the soil-water mixture.

2) UNCONFINED COMPRESSION TESTING

Unconfined Compression (UC) testing was used for fine-grained material treated with polymer emulsion. The Soil test stacking outline utilized in CBR testing was changed by trading the infiltration cylinder with a 4 inch plate.

ISSN: 2581-3404 (Online)
International Journal of Innovative Research in Technology and Management, Vol-5, Issue-3, 2021.

Tests were compacted in a 4 inch by 8 inch form utilizing adjusted delegate compaction. After compaction tests were expelled from the form and enveloped by a rubber film to keep abundance air from restoring the examples. A strain pace of 0.6 inches every moment was utilized with estimations taken each 0.01 creeps to an absolute strain of 15% (up to 1.23 inches). Sandy soils with an alternate pace of concrete blending were utilized and different rates of waterborne polymer were added to soils to research the compressive quality of balanced out examples. The dirt's were dried before utilizing in the blends. To start with, the necessary measures of polymer as a level of dry load of test and concrete were mixed and afterward added to dry soils. The measure of fluid polymer was picked as 2, 3, and 4% by all out weight of dry example and the measure of concrete was picked as 20, 30, and 40% by weight of dry example, separately. The blending test was put into the form. Following 24 hours after the fact, the examples were removed from the moulds and examples were put away in the relieving room at the temperature extending from 21 to 25 centigrade and afterward tried at 7 days. The polymer mixture was developed in to dough using proper Kneading by hand. The uniformly mixed dough was subsequently placed into a steel mould measuring 150 mm tall and 300 mm in diameter

IV. Results and Discussions

4.1 Unconfined Compression Test Results

The results of 7 days curing on unconfined compression strength results were shown in Figures 4.1and 4.2.The unconfined compression strength of stabilized samples increases with curing time. Both specimens containing polymer content of 2–4% by wt. % and cement content of 20–40 wt. % were cured in air during 7 days. So, by increasing the polymer contents, cross-linking between polymer networks increased and therefore the strength of soil increased. It is clear from figures that compressive strength of the stabilized soils was increased while increasing the curing time in air curing conditions.

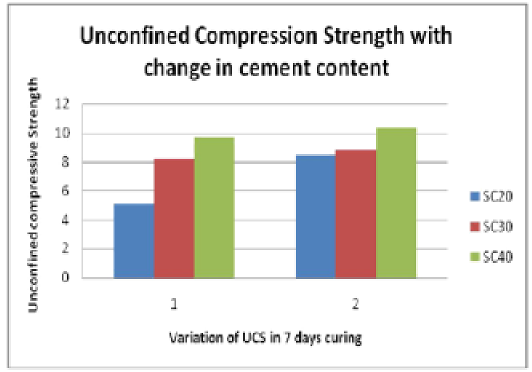

Figure- 2: Mix - SC20=Soil+20% cement SC30=Soil+30% cement SC40=Soil+ 40% cement

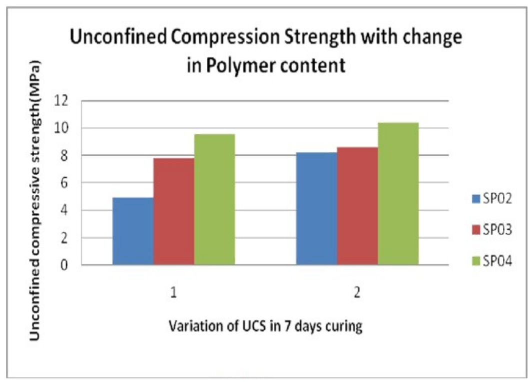

Figure- 3: Mix - SP02=Soil+2% Polymer SP03=Soil+3% Polymer SP04=Soil+4% Polymer

Table 5: Variation in Cement vs. polymer content

	Variation in cement content			Variation in Polymer Content		
Unconfined Compression Strength (MPa)	20%	30%	40%	2%	3%	4%
	5.1	8.2	9.7	4.9	7.8	9.56
	8.5	8.8	10.4	8.2	8.6	10.35

4.2 Unconfined Compression Test Results

ISSN: 2581-3404 (Online)
International Journal of Innovative Research in Technology and Management, Vol-5, Issue-3, 2021.

The result of CBR test of soil sample taken at 20% cement content and 2% polymer content under different times of soaking are presented in

- Figure – 4.3, Un-Soaked (0 day)
- Figure – 4.4, Soaked (1 day)
- Figure – 4.4, Soaked (2 days)
- Figure 4.5, Soaked (3 days)
- Figure – 4.6, Soaked (4 days)

Table 6: CBR Values for unsoaked 0 day

Soil with different Stabilizers	Penetration at	
	2.5 mm	5 mm
Soil without Stabilizers	45.40	44.91
Soil with Polymer 3%	52.55	54.55
Soil with cement 20%	57.66	59.56

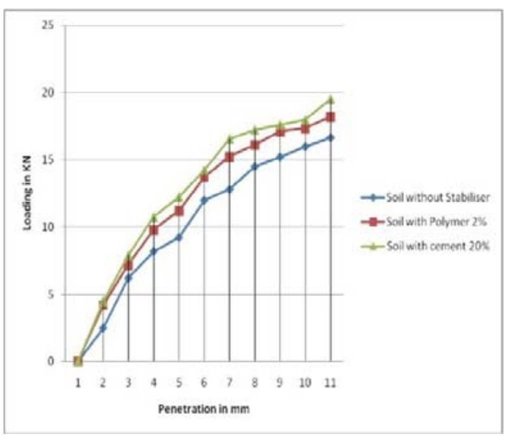

Figure 4: Unsoaked (0 day)

Table 7: CBR Values for soaked 1 day

Soil with different Stabilizers	Penetration at	
	2.5 mm	5 mm
Soil without Stabilizers	10.66	13.24
Soil with Polymer 3%	13.87	15.18
Soil with cement 20%	15.18	16.30

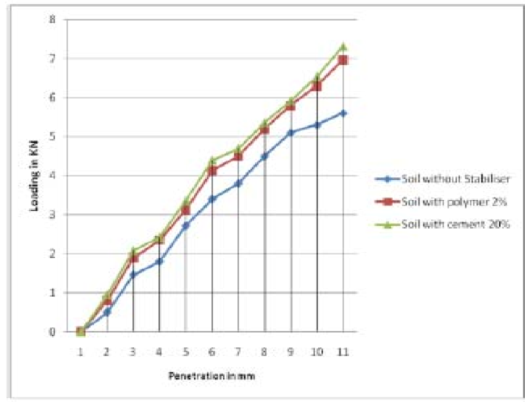

Figure 5: Soaked (1 day)

Table 8: CBR Values for soaked 2 day

Soil with different Stabilizers	Penetration at	
	2.5 mm	5 mm
Soil without Stabilizers	8.83	10.51
Soil with Polymer 3%	13.14	16.55
Soil with cement 20%	14.67	18.83

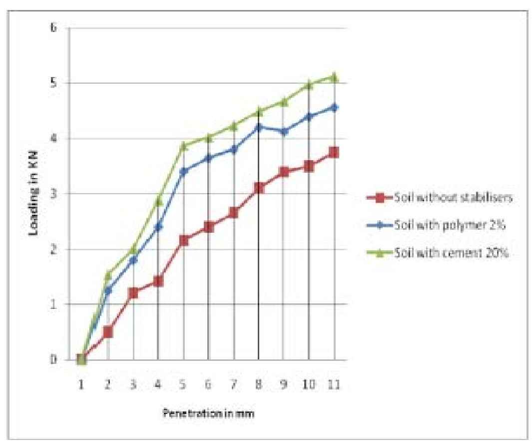

Figure 6: Soaked (2 days)

Table 9: CBR Values for soaked 3 day

Soil with different Stabilizers	Penetration at	
	2.5 mm	5 mm
Soil without Stabilizers	5.11	5.64
Soil with Polymer 3%	7.15	6.33
Soil with cement 20%	8.98	7.49

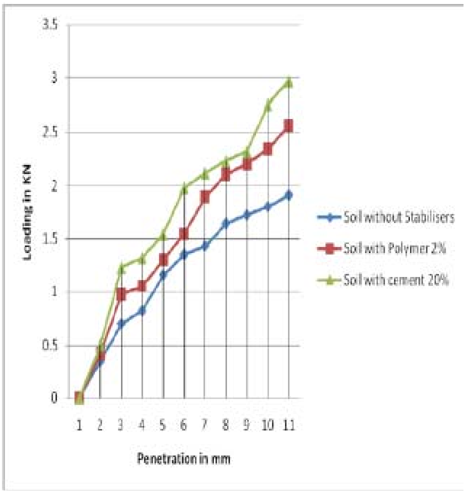

Figure 7: Soaked (3 days)

Table 10: CBR Values for soaked 4 day

Soil with different Stabilizers	Penetration at	
	2.5 mm	5 mm
Soil without Stabilizers	4.74	5.35
Soil with Polymer 3%	5.25	6.03
Soil with cement 20%	5.77	6.28

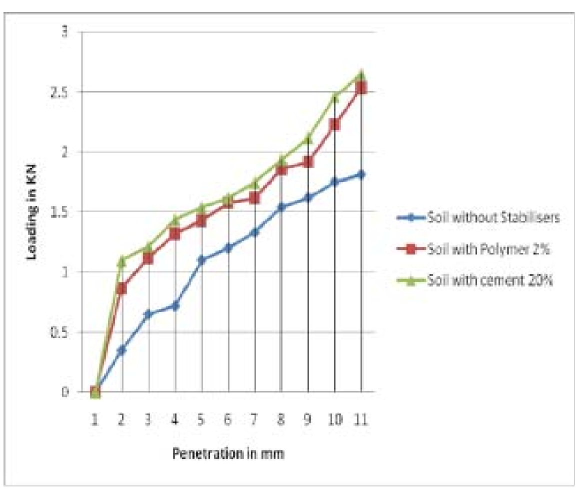

Figure 8: Soaked (4 days)

Table 11: Increase in CBR Values

Days of Soaking	0	1	2	3	4
S	44.91	13.24	10.51	5.64	5.35
SP02	54.55	15.18	16.55	6.33	6.03
SC20	59.56	16.30	18.83	7.49	6.28

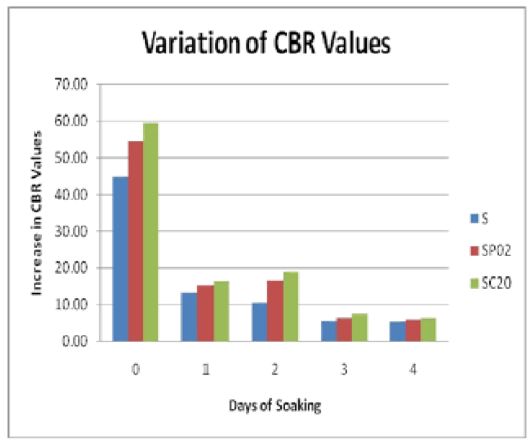

Figure 9: Variation in CBR Values with days of Soaking

4.3 Design of Flexible Pavement (IRC: 37-2012)

Assume Traffic Volume = 100 msa i.e, N = 100 msa
From IRC: 37-2012, At CBR=5.35,
Thickness of pavement = 714 mm At CBR = 6.03,
Thickness of pavement = 684 mm At CBR = 6.28,
Thickness of pavement = 675 mm
Decrease in Pavement thickness is as:
With polymer 2% = 30mm
With cement 20% = 39mm

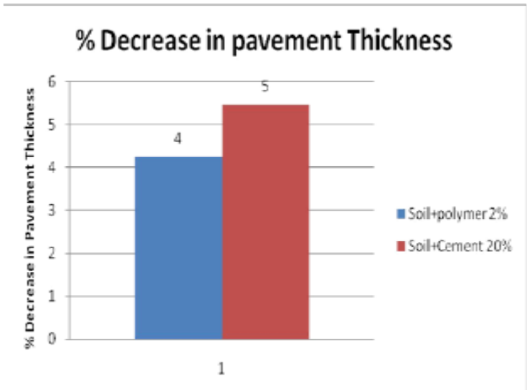

Figure 10: % Decrease in Pavement thickness

4.4 Analysis for Cost Of Pavement Per km Road Length

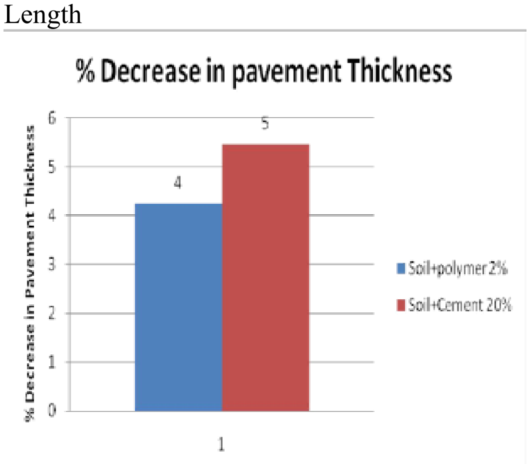

Figure 11: % Decrease in cost of Pavement

V. Conclusion

The results of the tests carried out in the present dissertation work are presented in following conclusions.

• The addition of polymer to the natural soil produced an improvement in its mechanical capacities that were determined by unconfined compression tests, from the first period of curing examination. From the strength aspect of liquefiable sandy soils, the optimum polymer content estimated polymer at 2%.

• The strength of sandy soil mixtures has increased with increment of cement contents up to about 30% and above 30% cement content; the strength of the soil almost becomes constant. This phenomenon is explained by the very fact that the fine grains of cement were covered and positioned around and among the sand grains.

• From Fig.4.1, it is clear that the increase in polymer content also increases Unconfined compressive strength of soil if it is maintained less than 4 %, this phenomenon is explained by the fact that increment of polymer and the polymer cover all of sample's area and increases cross-links And the impact on strength with variation in cement content and polymer content is not much.

• The increase in unconfined compressive strength is more at start of 20% cement addition in the sand, and then its increase is not much when cement content is increased.

• It has been observed that the CBR values increases with increase in cement and Polymer content, CBR values is much increased in the first and second days of Soaking but its values not increases much with increase in days of Soaking.

• CBR values have much impact when soil is stabilized with cement and polymer but cement and polymer content does not give many variations when their impact is observed closely.

• Polymer and cement addition into the clayey soil reduces the pavement thickness and hence the cost of pavement to a good extent.

VI. Scope for Future Study

Fly ash alongside another additive like lime, murrum, cement, and other such materials are often used together, and should be varied in quantity to get the simplest possible stabilizing mixture.

References

[1] IRC-37-2012, "Guidelines for the Design of Flexible Pavements" IRC, New Delhi.

[2] Jones, D. (2007). "Development of Performance-Based Tests for Nontraditional Road Additives," Transportation Research Record: Journal of the Transportation Research Board, 2(1989), 142-153.

[3] Kaniraj R, Gayathri V. Geotechnical behavior

of fly ash mixed with randomly oriented fiber inclusions. Geotext Geomembr 2003;21:123–49.

[4] Kumar A, Walia, Bajaj A. Influence of fly ash, lime, and polyester fibers on compaction and strength properties of expansive soil. J Mater Civil Eng ASCE 2007;19:242–8.

[5] Kumar S, Tabor E. Strength characteristics of silty clay reinforced with randomly oriented nylon fibers. EJGE 2003;127:774–82.

[6] Kolias et al,2005 Stabilisation of clayey soils with high calcium fly ash and cement. Cement & Concrete Composites 27 (2005) 301–313. Sciencedirect.com.

[7] McGown A, Andrawes Z, A1-Hasani M. Effect of inclusion properties on the behavior of sand. Geotechnique 1978;28:327–46

[8] Maher H, Gray H. Static response of sand reinforced with randomly distributed fibers. J Geotech Eng ASCE 1990;116:1661–77

[9] Murray J, Frost D, Wang Y. The behavior of sandy soil reinforced with discontinuous fiber inclusions. Trans Res Rec 2000;1714:9–17

[10] Maheshwari V. Performance of fiber reinforced clayey soil. EJGE 2011;16:1067– 87.

[11] N. O. Attoh-Okine,1995, Lime treatment of Laterite Soil. Construction and Building Materials, Vol. 9, No. 5, pp. 283-287, 1995 from Butterworth Heinmann

[12] Newman, J. K., and Tingle, J. S. (2004). Emulsion Polymers for Soil Stabilization, US Army Engineer Research and Development Center, Vicksburg, MS.

[13] Sayyed Mahdi Hejazi et al,2011, A simple review of soil reinforcement by using natural and synthetic fibers. Construction and Building Materials 30 (2012) 100– 116.

[14] Sahoo Biswajeet & Nayak Devadatta, (2009) "A Study of Subgrade Strength Related to moisture"

[15] Santoni, R. L., Tingle, J. S., and Webster, S.L. (2002). "Stabilization of Silty Sand with Nontraditional Additives." Transportation Research Record: Journal of the Transportation Research Board, 1787, 61-70.

[16] Sobhan K, Mashnad M. Tensile strength and toughness of soil–cement–fly ash composite reinforced with recycled high density polyethylene strips. J Mater Civil Eng ASCE 2002; 14:177–84.

[17] Soil Mechanics by KR Arora and Highway Engineering by Justo and Khanna.

[18] Tang C, Shi B, Chen W. Strength and mechanical behavior of short polypropylene fiber reinforced and cement stabilized clayey soil. Geotext Geomembr 2006;24:1–9

[19] Terzaghi, K., Peck, R., Mesri, G., (1996) "Soil Mechanics in Engineering Practice," 3rd Edition, Wiley-Interscience, :. 592

[20] Yıldız et al,2012 Effect of freezing and thawing on strength and permeability of lime-stabilized clays. Scientia Iranica A (2012) 19 (4), 1013–1017.