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Improving of Base Course Materials Characteristics using Industrial Wastes

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Abstract: Phosphogypsum is a solid by-product waste generated from phosphoric acid industry. This paper presents the effectiveness of mixing Phosphogypsum with crushed limestone to use this blend as road base course. Seven percentages (0, 5, 10, 15, 20, 25 and 30%) of Phosphogypsum were replaced from crushed limestone mixture dry weight. The influence of blending Phosphogypsum with crushed limestone was evaluated by preparing and testing mixture with several percentages of phosphogypsum and crushed limestone to determine some of their properties as maximum dry density, optimum moisture content, un-soaked California bearing ratio, soaked California bearing ratio, swelling percent and California bearing ratio after a series of wetting-drying cycles. The results indicate that the mechanical characteristics were improved by adding phosphogypsum to the crushed limestone mixtures.

***Index terms**: Phosphogypsum, Crushed limestone, Base course, California bearing ratio and Wetting-drying cycles.*

I. INTRODUCTION

In the wet process of phosphoric acid industry, the sulfuric acid attacks the ground phosphate rock; whereas, these components interact to form phosphoric acid and calcium sulfates; further, at filtration process the phosphoric acid separated as liquid product and calcium sulfate crystals as solid waste [1]-[3]-[4]. These crystals can exist in three types: Anhydrous crystals $CaSo_4$, Hemihydrate crystals $CaSo_4 0.5H_2O$ and dehydrate crystals $CaSo_4 2H_2O$ knowing as Phosphogypsum (PG) [3]. After filtration process, PG produced with moisture content about 18-35% [1]-[2].

Further, the PG quality and quantity varies depending on phosphate ore quality and manufacturing method that used in phosphoric acid industry [12]. However, about 4.5-5 ton of PG was generated per ton of phosphoric acid [1]-[2]-[3]-[4]. Moreover, the estimated worldwide amount of PG produced per year was ranging between 100 and 280 million ton [4]-[5]-[6].

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PG disposal process is a difficult and expensive process where required enormous effort and caused environmental problems [1]. There are three ways for disposing PG: wet stacking, dry stacking and charge it in seas and large rivers [1]-[2]. Whereas, the wet stacking requires vast lands and the stack design and construction requires intensive planning and engineering like shape, natural slope, specific gravity of PG, production rate of plant and expected stacking time [2].

On other side, in dry stacking the filtered cake of PG is transported by trucks and discharged in storage area in form of big stacks with high heights and this way cause problems on human and environment [1]-[2].

PG is a dark gray colored, tended to yellowish-brown [1]-[9]. Otherwise, it is fine-grained material [1]-[2]-[8]. Further, it is dump [1]-[2]-[8]. Whereas, the size and shape of granules differ according to size of phosphate granules used, concentration of phosphoric acid, amount of impurities, type of manufacturing process and temperature [2]. PG is composed of several elements with different ratios according to several factors, it is consists basically calcium sulfate crystals and it is similar to natural gypsum in its composition [1]-[15]. Further, it is consists small amounts of silica usually quartz, organic matter, traces heavy metals like fluoride, cadmium, chromium, lead and arsenic and trace radioactive elements like uranium and radium [1]-[2]-[8]-[9]. Therefore, PG classified as (TENOM) Technology Enhanced Naturally Occurring Material which technology enhanced material contains naturally occurring elements [3]-[11]. However, radon gas concentration has been measured in the surrounding soil and air of more than road constructed by using PG in Florida State before and under construction. Whereas, the results show that there is no noteworthy difference in radiation levels in the surrounding soil and in the road itself [12]. PG can be used as fertilizer which good source of calcium, sulfate and phosphor [3], in sulfuric acid industry [7], as cement retarder [3]-[7] and in gypsum-board industry [3]-[7]. Moreover, PG can be reused as highway construction aggregate in granular and asphaltic layers [7]-[14]. Whereas, it is used in highways construction in some countries like: USA, France and Japan [3]. In USA - Miami, a study was carried out on using of PG in secondary road construction. Therefore, two roads have been constructed in Florida State one of them in Polk County with length 1.5 mile and the other in Colombia County with length 2 miles. Whereas, Polk road constructed by using dehydrate PG (DHPG) while Colombia road constructed by using hemihydrate PG (HHPG).

Therefore, mixture created from DHPH plus sand with ratio 1:2 (DHPG : Sand) with 7% moisture content and compacted by modified Proctor test gives unconfined compressive strength (UCS) 1103.16, 586.05 and 282.68 kilo Pascal KPa at 28, 7 days and directly after compaction, respectively; otherwise, samples collapsed when it submerged in water; moreover, laboratory California bearing ratio (CBR) without immersion reached about 68% and field CBR reached about 66%. On the other hand, mixture created from HHPG plus sand with ratio 2:1 (HHPG : sand) with 9.5% moisture content by modified Proctor test gives UCS 1654.74, 861.84 and 448.15 KPa at 28, 7 days and directly after compaction, respectively. Moreover, laboratory CBR without immersion reached to 79% and field CBR reached to 65%. In addition, the CBR ratio of mixture consists only DHPG was 35% and for mixture contains HHPG only was 100% while the CBR for sand was 27% [10]-[12].

In USA - Louisiana, it has been proved that PG can be used in construction of road base and sub base; where, tests results demonstrated that mixtures containing sand, PG and cement have UCS directly increasing with both of compaction energy, curing age, cement percent and cement type where it is an important factor in UCS variation and sulfate resistance cement is preferable [16].

In India, tests were conducted on mixtures of PG, lime and Fly ash to be used in road base and sub base construction; therefore, the characteristics of raw materials and formed mixtures were determined. However, mixture consisting 2%PG, 8% lime plus 90% fly ash satisfies the requirement of road base and sub base construction, where results showed an increasing in UCS, split tensile strength and CBR with curing age [17].

II. MATERIALS

A. Crushed limestone

The sample of crushed limestone (CLS) was collected from Jabal Alkorimat located in Giza – Egypt; whereas, the sample was brought from Zahraa Al Maadi stockpile – Cairo city in 25 bags each bag weighs about 40 kg; further, the maximum particle size of the sample of limestone are 50 mm. However, the sample was tested in Roads Lab in Ain-Shams University to determine its characteristics and to check its validity as base course material.

B. Phosphogypsum

The sample of PG was brought from Abu-Zaabal plant for fertilizers industry located in Kaliobeya – Cairo where the factory produce about 500 thousand ton per year of PG. The total weight of the sample is 1 ton distributed to 20 bags where each bag weights about 50 kg. Whereas, the obtained sample was aged to approximately 6 month in dry stack; further, the sample has moisture content between 13-15%.

Furthermore, the chemical analyses of the used local PG as received from the manufacture are shown in the table 1. However, the sample was tested in Roads Lab in Ain-Shams University to determine its characteristics.

Table 1: The chemical analysis of the PG sample as received from the Abu Zabaal plant.

Item	Results w/w%	
Moisture	15	30
Water soluble P_2O_5	0.5	0.32
Total P_2O_5	1.4	1.34
Water soluble calcium	6	5.1
Total calcium	22	21.1
Water soluble sulfur	13	12.12
Total sulfur	17	15..92
SiO_2	7	6.15
Fe_2O_3	0.31	0.21
MgO	0.09	0.07
Al_2O_3	0.06	0.04

III. METHODS

The main goal of this research is improving the characteristics of locally available base course materials by mixing these materials with locally available industrial wastes and testing these mixtures according to the American Association of State Highway and Transportation Officials AASHTO; therefore, the experimental program is divided to two parts:

Part one based on collecting and testing CLS and PG according to the standard tests stated in the American standard AASHTO to determine some of its physical and mechanical characteristics such as gradation, natural water content, liquid limit, plastic index, percent of fines, unit weight, water absorption, optimum moisture content and maximum dry density, flakiness and elongation indexes, abrasion resistance, soundness resistance, un-soaked and soaked bearing capacity and swelling percent to judge on its validity as road base materials; however, table 3 showing the characterization tests conducted on the different materials.

Part two based on preparing and testing mixtures of CLS and PG with PG ratios 0, 5, 10, 15, 20, 25 and 30% from mixture dry weight. Therefore, the mixtures were tested according to AASHTO to obtain their characteristics and to compare between their characteristics. However, basic tests were conducted on mixtures to determine the optimum moisture content (OMC), the maximum dry density (MDD), the un-soaked CBR, the soaked CBR and the swelling ratio to monitor the effect of adding PG to CLS mixtures on the previous characteristics. Further, depending on the results of previous tests the control mixture and the mixture with maximum CBR were subjected to CBR test after series of wetting – drying cycles to check the durability of the control and the prepared mixture by determining the effect of wetting – drying cycles on their bearing capacity. Furthermore, to check the durability of each of CLS and PG separately, five samples of 100% PG and like them of 100% CLS were prepared according to AASHTO T-193 and subjected to various number of wetting - drying cycles; whereas, after the first wetting – drying cycle one sample of the PG was removed from water, extracted from the mold, dried, mixed with un-soaked CLS at ratio 20%PG:80%CLS and tested according to AASHTO T-193 where this process repeated at 2, 3, 4 and 5 wetting – drying cycles. Conversely, the soaked CLS samples were mixed with un-soaked PG.

Table 2: The ratios of the different materials used to form the limestone mixtures.

Mixture ID	100LS	95L5P	90CL10P	85L15P	80L20P	75L25P	70L30P
PG %	0	5	10	15	20	25	30
CLS %	100	95	90	85	80	75	70

IV. RESULTS AND DISCUSSION

A. Materials characterization tests

After importing CLS and PG samples, the samples were subjected to basic characterization tests according to AASHTO; whereas, table 3 presents the results of these tests:

Table 3: The results of the characterization tests conducted on the different materials.

Property		CLS	PG	Standard
Natural water content %		0.78	13.05	AASHTO T255
Liquid limit % Plastic index %		24.25 2.55	24 1.5	AASHTO T89 AASHTO T90
Percent of fines passing #200 sieve	dry	0.45	-	AASHTO T11
	wash	9.2	90	
Percent of fines using sand equivalent		31	9	AASHTO T176
Grading		x	-	AASHTO T27
Unit Weight gm/cm3 Water Absorption %		2.05 9.93	1.92 8.1	AASHTO T84 AASHTO T85
MDD gm/cm3 OMC%		2.075 10	1.66 14	AASHTO T180
Flakiness% Elongation %		22.4 25.7	-	BS 812-105.1 BS 812-105.2
Abrasion resistance%		48.3	-	AASHTO T96
Soundness resistance%		7.63	-	AASHTO T104
Un-soaked CBR%		65.57	100	AASHTO T193
Soaked CBR%		59.9	70	AASHTO T193
Swelling %		0.2	2.27	AASHTO T193

B. Mixtures characterization tests

The samples of crushed limestone were reduced by using mechanical splitter according to method A in AASHTO T-248; further, mixtures of CLS and PG with ratios 0 – 5 – 10 – 15 – 20 – 25 – 30% from mixture dry weight were prepared to be tested according to method D in AASHTO T-180 to illustrate the effect of adding PG on optimum moisture contents and maximum dry densities of CLS mixtures which compacted in 6 in. mold in 5 layer in order of 56 blows per layer using 4.54 kg rammer dropped from 45.7 cm; whereas, figure 1 showed the moisture-density relationships of prepared CLS mixtures and the results of compaction tests presented in table 4.

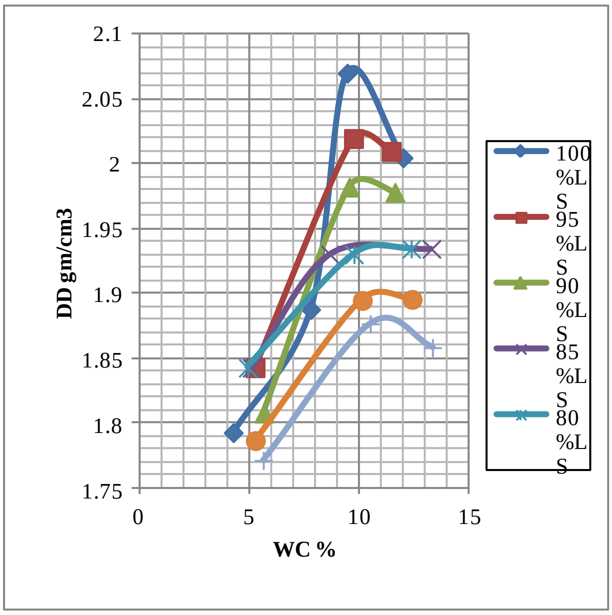

Figure 1: the moisture-density relationship of mixtures containing CLS and PG.

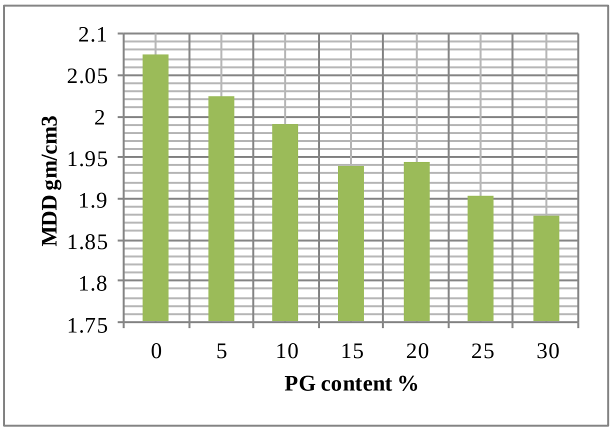

Figure 2: the relationship between MDD and PG % of prepared CLS mixtures.

As showed in figure 2 and figure 3, the maximum dry density of prepared CLS mixtures increased with increasing CLS content and decreased with increasing PG content because PG has unit weight lower than CLS; on the other hand, the optimum moisture content of prepared CLS mixtures increased with increasing PG content and decreased with increasing CLS content because adding PG to CLS increases the surface area of mixtures aggregates. Further, twelve samples were prepared in the same manner of preparing samples in compaction test where the mixtures were compacted at optimum moisture contents and maximum dry densities in standard CBR mold with 6 in. diameter in 5 layers in order of 56 blows per layer using 4.54 kg rammer dropped from 45.7 cm. Therefore, the mixtures were tested according to AASHTO T-193 where six samples were tested immediately after compaction and six samples were submerged for 96 hour to obtain the effect of adding PG on CBR of CLS mixtures in un-soaked and soaked state also to determine the swelling percent and the optimum PG content.

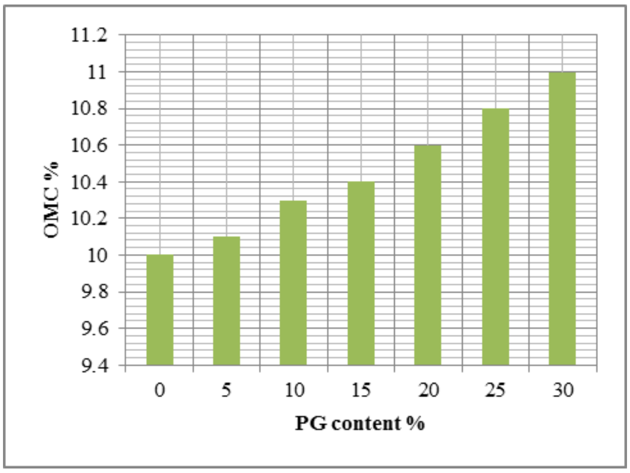

Figure 3: the relationship between OMC and PG % of prepared CLS mixtures.

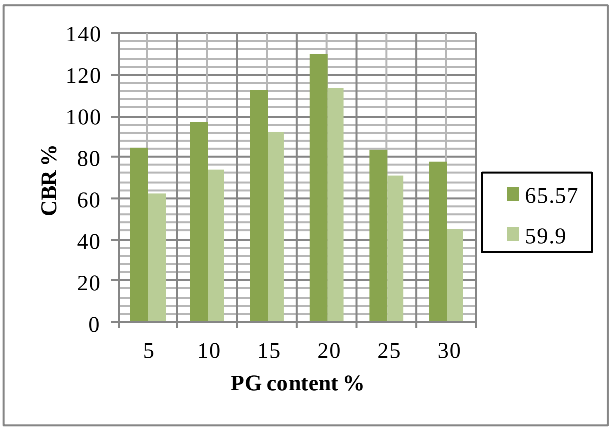

Figure 4: the relationship between CBR % and soaked CBR and PG % of prepared CLS mixtures.

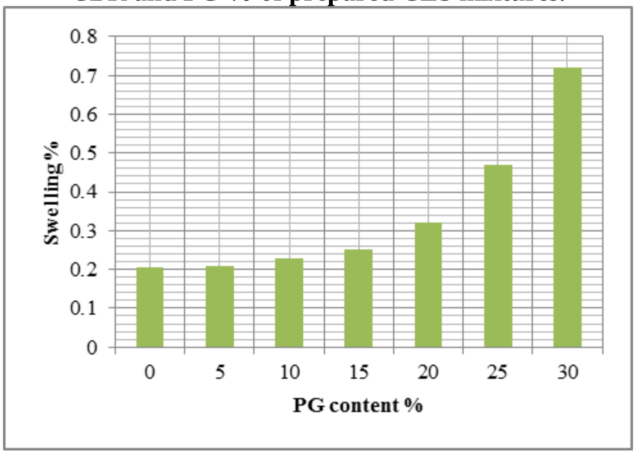

Figure 5: the relationship between swelling % and PG % of prepared CLS mixtures.

As shown in Figure 4, the results of CBR tests conducted immediately after compaction showed that the CBR of CLS mixtures increased with increasing PG content from 5% up to 20 % and decreased at higher percentages of PG. On the other hand, the CBR values of samples submerged for 96 hour then subjected to penetration test were decreased comparing with samples without soaking.

As shown in figure 5, the swelling percent of CLS mixtures increased with increasing PG content. Whereas, the results of un-soaked CBR, soaked CBR and selling tests are presented in table 4.

Further, the mixture of 80% CLS + 20% PG with the highest CBR% was subjected to a series of wetting-drying cycles to illustrate its durability by determining the effect of wetting-drying cycles on its CBR%; therefore, a seven samples of 80L20P were prepared as previous samples in the same manner and conditions and according to AASHTO T-193; however, this samples subjected to different number of wetting – drying cycles then subjected to CBR penetration test; beside, a seven samples of control mixture 100% CLS were prepared and tested in the same way.

As shown in figure 6, the results showed that CBR value decreased with increasing in number of wetting – drying cycles for control and 80L20P samples until number of wetting – drying cycles reaches five cycles where the CBR values of control and 80L20P samples were not decreased for higher number of cycles than five. Further, the results are shown in table 5.

Furthermore, the durability of PG and CLS was evaluated separately by preparing five samples of PG only and other five of CLS only according to AASHTO T-193; whereas these samples compacted and subjected to five wetting-drying cycles; whereas, one sample of PG and one sample of CLS were removed from water after the 1st cycle, extracted from the mold and oven-dried at 60 C° for PG and 105 C° for CLS then the soaked-dried PG for one cycle blended with un-soaked CLS at ratio 20%PG:80%CLS and tested according to AASHTO T-193 where this process repeated at the 2nd, 3rd, 4th and 5th cycles; on the contrary, the soaked-dried CLS sample were blended with un-soaked PG and tested in the same way. Otherwise, the results are shown in table 6.

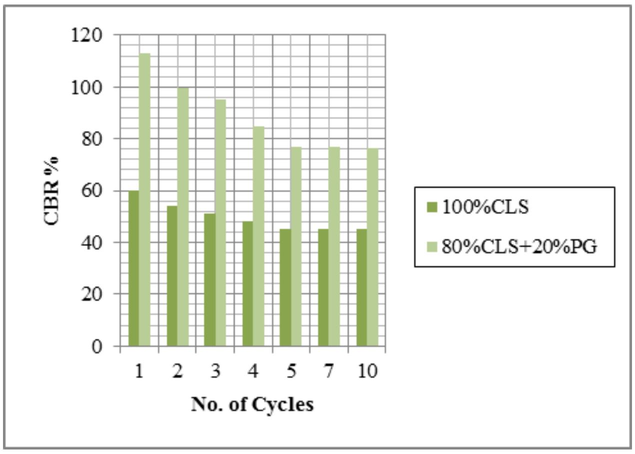

Figure 6: the relationship between CBR % and no. of wetting-drying cycles of 80L20P and 100L samples.

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Table 4: the results of CBR tests conducted on CLS+PG mixtures.

Mixtures/Tests		Un-soaked	Soaked		Compaction	
Sample ID	**CLS to PG Ratio**	**CBR%**	**CBR%**	**Swelling %**	**MC%**	**DD gm/cm3**
100L	-	65.57	59.9	0.206	10	2.075
95L5P	95:5	84.7	62.1	0.21	10.1	2.025
90L10P	90:10	97.2	73.5	0.23	10.3	1.99
85L15P	85:15	113.05	92.7	0.25	10.4	1.94
80L20P	80:20	130.01	113.1	0.32	10.6	1.944
75L25P	75:25	83.6	71.2	0.47	10.8	1.904
70L30P	70:30	78	45.2	0.72	11	1.88

Table 5: the results of CBR tests conducted on 20%PG+80%CLS mixtures and 100% CLS mixtures subjected to wetting-drying cycles.

Mixture	CBR% per no. of wet – dry cycles						
	1	**2**	**3**	**4**	**5**	**7**	**10**
100L	59.92	54.26	50.87	48.05	45.22	45.22	45.22
80L20P	113.05	99.48	94.96	84.79	76.87	76.87	76.31

Table 6: the results of CBR tests conducted on mixtures containing soaked-dried PG and mixtures containing soaked-dried CLS according to no. of wetting-drying cycles.

Mixture		CBR% per no. of wet – dry cycles				
20% PG	**80% CLS**	**1**	**2**	**3**	**4**	**5**
S-D PG	**CLS**	113.1	104.1	101.7	100.6	96.1
PG	**S-D CLS**	79.14	75.74	70.1	61.1	53.1

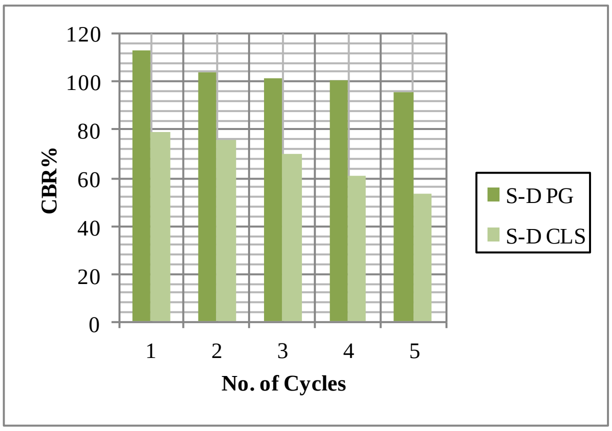

Figure 7: the relationship between CBR % of mixture containing soaked-dried PG, mixtures containing soaked-dried CLS and no. of wetting-drying cycles.

As shown in figure 7, the CBR of 20%PG+80%CLS mixture deceased if any component subjected to wetting-drying cycles; whereas, the CBR of mixture containing PG subjected to one wetting-drying cycle and un-soaked CLS decreased comparing with mixture containing PG and CLS without any soaking process; furthermore, the CBR of PG and CLS mixtures decreased with increasing in number of wetting-drying cycles which PG subjected to it.

On the other hand, the CBR of mixture containing CLS subjected to one wetting-drying cycle and un-soaked PG decreased comparing with mixture containing PG and CLS without any soaking process also with mixtures containing PG subjected to wetting – drying cycles and CLS in normal state; beside, the CBR of PG and CLS mixture decreased with increasing in number of wetting-drying cycles which CLS subjected to.

However, the CBR values of mixture containing PG subjected to soaking-drying cycles were higher than the CBR values of mixture containing CLS subjected to soaking-drying cycles; whereas, the CBR of mixtures including soaked-dried PG decreased about 15% from the 1st cycle to the 5th cycle and about 13% comparing with the CBR of mixture containing PG and CLS without any soaking process while the CBR of mixture including soaked-dried CLS decreased about 32.9% from the 1st cycle to the 5th cycle and about 39.1% comparing with the CBR of mixture containing PG and CLS without any soaking process.

CONCLUSION

With respect to results obtained from this study the following conclusion can be accessed:

1) It can be concluded from the results of modified compaction test conducted on CLS and PG mixtures that the maximum dry density of these mixtures declined with increasing in PG percent; beside, it has been noticed that the optimum moisture content of these mixtures increased with increasing in PG percent comparing with control sample consisting 100% CLS.
2) Further, it has been observed from the results of un-soaked CBR test conducted on CLS and PG mixtures that the un-soaked bearing capacity of these mixtures improved with increasing PG percent until the PG percent reach 20% of CLS mixture dry weight and decreased at PG percentages higher than 20%; on the other hand, the bearing capacity of these mixtures adversely affected by soaking for 96 hour where the soaked CBR of these mixtures decreased comparing with the un-soaked CBR of same mixtures; therefore, the optimum PG content was 20% based on that the mixture containing 20%PG and 80%CLS has the higher un-soaked and soaked CBR; moreover, the swelling percent of CLS and PG mixtures increased with increasing in PG percent.

3) Furthermore, it has been noted that the CBR of the mixtures of 20%PG+80%CLS and 100%CLS decreased with increasing number of wetting-drying cycles that conducted on these mixtures before testing until number of wetting – drying cycles reaches 5 cycles where the CBR values of control and 80L20P samples were not decreased for higher number of cycles than five.
4) In addition, it has been noticed from preparing samples of 100%PG mixture and 100%CLS mixture and subjecting these samples to number of wetting-drying cycles then drying and blending the soaked PG with un-soaked CLS also the soaked CLS with un-soaked PG at ratios 20%PG:80%CLS that the CBR of soaked PG mixtures decreased with increasing in number of wetting-drying cycles that PG subjected to it comparing with the CBR of mixture consisting PG and CLS without any soaking process at ratio 20%PG:80%CLS; on the other side, the CBR of soaked CLS mixtures decreased comparing with the CBR of soaked PG mixtures which indicates that CLS adversely affected by wetting-drying cycles more than PG.

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