Strength and consistency behaviour of replacement of cement with silicate-based geopolymer cement modified soft soil treated with crushed waste glasses for pavement underlain

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Érkezett: 2020. 01. 23. ▪ Received: 23. 01. 2020. ▪ <https://doi.org/10.14382/epitoanyag-jsbcm.2020.31>

Abstract

The effect of quarry dust based geopolymer cement (QDbGPC) and ordinary Portland cement (OPC) replaced in the ratios of 0:0, 0:40, 5:35, 10:30, 15:25, 20:20, 25:15, 30:10, 35:5, and 40:0% by weight respectively was investigated. This was carried out under the influence of 4%, 8%, 12%, 16% and 20% by weight crushed waste glasses. This was conducted to study the effect of these materials on the consistency and strength characteristics of representative test soil in the laboratory. Preliminary test on the test soil shows that the soil is expansive, highly plastic with high clay content and classified as an A-7-6 soil group according to AASHTO classification system. It is also classified as poorly graded according to USCS. The treated exercise presented an improvement in the California bearing ratio, compaction and consistency characteristics in a steady and substantial pattern. The increased addition of the proportions of geopolymer cement caused increased values of CBR, G_s and decreased values of plasticity index. The unsuitable and problematic soft soil was improved to meet the requirements for a soil material to be used as a subgrade construction material. This is due to the composite blend of materials with high silicate contents responsible for strength gain. However, the replacement of ordinary Portland cement with silicate-based geopolymer cement will remove the dangers of CO₂ emission during construction works and present an environmentally friendly practice of soil re-engineering.

Keywords: California bearing ratio, compaction, silicate-based materials, crushed waste glasses, geopolymer cement, recycled solid waste materials, composite construction materials

Kulcsszavak: kaliforniai teherbírási érték, tömörítés, szilikát alapú anyagok, zúzott üveghulladék, geopolimer cement, újrhasznosított szilárd hulladékok, kompozit építőanyagok

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1. Introduction

The improvement of the mechanical properties of soft soils has become increasingly necessary because of the role soils play in pavement constructions, more especially the underlain foundation structures [1-2]. Pavements are underlain structurally by soils borrowed or compacted in situ, during the foundation phase of flexible or rigid pavements [3-6]. Pavement facilities are important horizontal structures that contribute to the socioeconomic development and environmental accessibility of suburbs, urban centres, cities and nations. Unfortunately, in Nigeria and many other developing countries of the world, the failure rate of pavements is alarming [7]. Over 80 percent of the road pavements in Nigeria are in deplorable state due to primarily badly formed underlain. Worst in this category is located in the south-eastern and southern geopolitical regions of the country [8-9]. Pavement failures are initiated primarily by lateral deformation, which eventually initiate cracks like as presented in Figs. 1 & 2 [2, 10]. These cracks give way for moisture migration to the underlain structure of the pavements. Further intake of moisture under hydraulically bound conditions causes the underlain subgrade to experience volume changes due swell-shrink cycles [11-12]. According to Herve *et al.* [1], these volume changes initiate greater degree of failure by shear and lateral heaving. This is the consequence of building pavements with weak and unstable underlain subgrade soils [1, 13-17]. The use of ordinary Portland cement in the weak soil stabilization protocols, on the other hand, generates strengthened structures prone to crack effects because of the brittle nature of ordinary cement stabilized soils [18]. Moreover, the use of ordinary Portland cement releases an equivalent amount of CO₂ into the atmosphere contributing to global warming and this is at a time when our planet is at the brink of environmental issues as a result of constant exposure to nonenvironmentally friendly construction procedures and practices [19-23]. The synthesis of geopolymers with quarry dust as the base material and its utilization in the improvement of the soft soil properties is currently being studied [23-29]. Soil conservation takes many methods and forms depending on its usage and various environmental reasons. This has proven as a sure way of conserving the soils for use as engineering material. However, new and other areas are also being explored to achieve soil stabilization with zero release of CO₂ into the environment [30-35]. Crushed waste glasses, also, are eco-friendly geomaterials derived from crushing waste glasses disposed by Glass Industries as scrap losses from glass production or poor handling [1, 36]. Waste glasses are also solid waste disposed by factories, homes and offices resulting from poor handling, accidents, etc. The utilization of ordinary Portland cement (OPC) and quarry dust based geopolymers (QDbGPC or GPC) in this work in a linear inverse replacement pattern was to determine the best geoengineering practices through which silicate-based or bio-based cements can partially or totally replace Portland cements, which inadvertently allow room for the disposal of the solid waste under consideration without exposing the environment or landfills to potential dangers [37-39]. This was conducted in that order to determine the replace-ability of

the silicate-based geopolymer cement over ordinary Portland cement [2]. Also, the effect of introducing crushed waste glasses in an incremental order into the cemented test soil was also studied. It was a complex blending of various eco-friendly materials with a view to improving the California bearing ratio, consistency and compaction characteristics of the treated soft soil. According to Herve *et al.* [1] and Onyelowe *et al.* [36] the best practices of soil conservation could take this pattern for soils to be used as pavements underlain.

Fig. 1 Cross section of pavement with crack propagation at subgrade failure under traffic cyclic loading [2]

1. ábra Az útpálya keresztmetszete valamint a repedés terjedése az aljazat meghibásodásakor ciklikus forgalmi terhelés esetén

Fig. 2 Plan of pavement with crack propagation at subgrade failure under traffic cyclic loading [2]

2. ábra Az útpálya felülnézete valamint a repedés terjedése az aljazat meghibásodásakor ciklikus forgalmi terhelés esetén

2. Materials and methods

2.1 Materials preparation

400 g of test lateritic soil was collected from distributed in hilly areas such as Soc Son District, Hanoi City and Hoa Binh Province of Vietnam. The disturbed sample was taped to remove lumps, sundried for 4 days and stored for the stabilization experimentation. The quarry dust material is in several Crush Rock Industries Areas in Ninh Binh Province such as Gia Vien District, Hoa Lu District, Hanoi, Vietnam, which satisfies design conditions in accordance with TCVN

8857 [39]. It was also sundried to remove moisture and stored in silo bags for use. The waste glasses were collected from the dump sites across Hanoi. They were crushed with the 50kN crusher and also stored for use. The OPC used satisfied the requirement of cements used as binders in Vietnam construction industry [40-41]. The geopolymer cement (GPC) was synthesized with quarry dust (QD) and activator materials (Sodium Hydroxide (NaOH) and Sodium Silicate (Na_2SiO_3)). Based on previous findings on the synthesis of GPCs [28, 29, 31, 42-47], the quarry dust based Geopolymer was synthesized.

2.2 Experimental methods

The conventional tests that were conducted on the test soil for characterization and classification reasons are as follows;

- Particle size distribution (PSD): this was conducted with vertically arranged sieve sizes mounted on an automatic shaker in accordance with BS 1377-2 and Nigerian General Specification [7, 48],
- Standard Proctor Compaction: this was conducted on the untreated soil with 2016 ELE Automatic Compactor Machine in accordance with BS 1377-2, and NGS [7, 48] and on the treated soil in accordance with BS 1924 [49],
- Consistency Limits: this was conducted using a 2013 cassagrande apparatus on the untreated soil in accordance with BS 1377-2, and NGS [7, 48] and on the treated soil specimens in accordance with BS 1924 [49],
- Specific Gravity test was conducted by Pycnometer method in accordance with BS 1377-2, and NGS [7, 48] and BS 1924 [49] for the untreated and the treated soils respectively,
- Chemical Oxides Composition test on the test soils and the test materials with XRF method in accordance with BS 1377-2 and Nigerian GS [7, 48]
- And finally, California Bearing Ratio test (CBR): was conducted on the untreated and treated soils blended with 4, 8, 12, 16, and 20% CWG and linearly inversely replaced cements of QDbGPC and DOPC in a ratio pattern of 0:40, 5:35, 10:30, 15:25, 20:20, 25:15, 30:10, 35:5, and 40:0% by weight of solid. This was experimented with a 2015 S211 KIT CBR penetration machine, motorized 50kN ASTM used to load the penetration piston into the soil sample at a constant rate of 1.27 mm/min (1 mm/min to BS Spec.) and to measure the applied loads and piston's penetrations at determined intervals with which CBR values were computed using Eq. (1) and results were obtained. This was experimented in accordance with British standards, Vietnamese standards and AASHTO methods [48-54]

$$CBR = \frac{P_T}{P_S} \times 100 \quad (1)$$

Where;

P_T = corrected unit test load corresponding to the chosen penetration from load penetration curve,

P_S = the total standard load for the same depth of penetration which can be taken as 13.24 kN for 2.5 mm penetration and 19.96 kN for 5.0 mm penetration.

3. Results and discussions

3.1 General behavior and classification of test materials

The results of the experimental program have been presented in tables and graphs in the following pages. Test soil sample was investigated and characterized under the laboratory conditions with the preliminary test results presented in *Tables 1*, and *2* and *Fig. 3*. The soil was classified as A-7-6 group according to the AASHTO classification method [51]. It was equally classified according to USCS as poorly graded (GP) soil. Additionally, the soil was observed as having high clay content and high free swell index (FSI). It was also classified as highly plastic with plasticity index above 17% and expansive. *Table 3* presents that the test materials have high aluminosilicate content and possess pozzolanic properties [40]. *Table 3* and *Fig. 4* presents the oxide rates and bonding potentials of the test materials. This also satisfied that the material bonding is a very important factor in soil stabilization and strength development. This is because the soil and the admixture need to form a homogeneous and cohesive bond. Material requirement for cementitious materials states that the sum of the oxide rates of SiO_2 , Al_2O_3 , and Fe_2O_3 should not be less than 70%. The results of the analysed materials presented in *Table 3* show that the percentage of $\text{SiO}_2 + \text{Fe}_2\text{O}_3 + \text{Al}_2\text{O}_3$ for each of the materials is greater than 70%. This behaviour makes the test material samples highly pozzolanic [40]. This property was of great advantage because it brought about a high degree of interaction, pozzolanic reaction, carbonation reaction and bonding between the studied soil and the synthesized GPC.

Property description of test soils and units	Values
% Passing Sieve No 200	38
NMC (%)	13.49
LL (%)	46
PL (%)	21
PI (%)	25
SL (%)	8
FSI (%)	234
G_s	2.43
AASHTO Classification	A-7-6
UCSC	GP
MDD (g/cm^3)	1.85
OMC (%)	16.2
CBR (%)	13
Colour	Reddish Grey

Table 1 Basic properties of test soils
1. táblázat A vizsgált talajok alapvető tulajdonságai

Materials	% Passing sieve (mm)										
	19	6.35	4.75	2.36	1.18	0.6	0.425	0.3	0.15	0.075	Pan
Test Soil	-	100	91	82	63	50	39	28	21	10	0
Quarry Dust	100	89	44	23	18	15	14	12	5	2	0
CWG	100	96	82	76	63	54	47	39	24	19	0

Table 2 Particle size distribution (PSD) of test materials
2. táblázat A vizsgált anyagok szemmegoszlása

Materials	Oxides Composition (content wt %)											
	SiO ₂	Al ₂ O ₃	CaO	Fe ₂ O ₃	MgO	K ₂ O	Na ₂ O	TiO ₂	LOI	P ₂ O ₅	SO ₃	IR
Test soil	76.56	15.09	2.30	2.66	0.89	2.10	0.33	0.07	-	-	-	-
Quarry Dust	63.48	17.72	5.56	1.77	4.65	2.76	0.01	3.17	0.88	-	-	-
CWG	73.5	0.78	8.11	-	1.79	2.09	11.0	-	1.89	-	-	-
DOPC	21.45	4.45	63.81	3.07	2.42	0.83	0.20	0.22	0.81	0.11	2.46	0.16

*IR is Insoluble Residue, LOI is Loss on Ignition, QD: Quarry Dust, DOPC: Dangote Ordinary Portland Cement, CWG: Crushed Waste Glasses

Table 3 Oxides composition of the materials used in this paper
3. táblázat A cikkben használt anyagok oxidos összetétele

Fig. 3 Particle size distribution of studied materials
3. ábra A vizsgált anyagok szemmegoszlása

Fig. 4 Chemical oxides components in studied materials
4. ábra A vizsgált anyagok kémiai oxidos összetétele

3.2 Compaction behaviour of QDbGPC: DOPC treated soil with crushed waste glasses (CWG)

The compaction results are presented in Table 4 and Fig. 5. The compaction behaviour is the densification process observed on the QDbGPC/ DOPC treated soil under the influence of added proportions of crushed waste glasses. The test soil was observed to be an unstable soil and was treated alternately with QDbGPC and DOPC in the ratios of 0:0, 0:40, 5:35, 10:30, 15:25, 20:20, 25:15, 30:10, 35:5, and 40:0% respectively. The effect of 4%, 8%,

12%, 16% and 20% by weight of crushed waste glasses over the cemented test soil was also observed. While 0:0% of the cements proportion by weight of solid served as the control point, the proportions of GPC increased from 5% in an increment of 5% while DOPC decreased from 40% at the rate of 5% also. The maximum dry density of the test soil increased with increased proportion of GPC and decreased proportion of DOPC. This consistently continued until 40:0% corresponding to GPC and DOPC respectively. The specific gravity also increased in that succession consistently. Alternatively, the optimum moisture content decreased with the same pattern. Notably, the introduction of the high content aluminosilicate crushed waste glasses improved the compaction characteristics of the test soil under the influence of the cements. This behaviour on the axes of the cements linear inverse replacement process was due to the introduction of a more bio-based cementing material, which is resistant to sulphate attacks, cracking and brittleness. Also, the bio-based cementing geopolymer i.e. the QDbGPC composite produced more silicate and aluminate to form CSH and CAH responsible for strength gain and densification [2, 56, 57, 58, 59]. It forms more elastic agglomeration and sequestrum and flocs to produce a more densified treated soil. Cation exchange reactions between the dissociated ions from the bio-based cementing material caused the increased density and specific gravity with increased proportions of GPC. These increased MDD were obtained at optimum moisture content [60].

3.3 Consistency behaviour of QDbGPC to DOPC treated soil with crushed waste glasses (CWG)

Table 5 and Fig. 6 present the consistency behaviour of the quarry dust based geopolymer cement linearly and inversely replace ordinary Portland cement treated soil under laboratory conditions under crushed waste glasses added to the treatment procedure. The addition of CWG into the cemented soil reduced the liquid limits, plastic limits and the plasticity index consistently. This behaviour however shows that further addition of CWG beyond the maximum 40% utilized in this exercise could have improved the consistency limits further. But very important to note was the improvements recorded with the linearly inversely introduction of the cements into the test soil. That is, while the bio-based geopolymer cement was increased in the treatment blend, the Portland cement was reduced and the effect of this treatment pattern was observed. Results have shown that increased quarry dust based geopolymer cement reduced the consistency limits from very high plastic condition to even very less plastic consistency. The

Proportion of Geopolymer to Ordinary Portland Cements (GPC/OPC)	Percentage of Crushed Waste Glasses (CWG) added (%)																	
	0%			4%			8%			12%			16%			20%		
	MDD	OMC	Gs	MDD	OMC	Gs	MDD	OMC	Gs	MDD	OMC	Gs	MDD	OMC	Gs	MDD	OMC	Gs
0:0	1.85	16.2	2.43	1.87	16.1	2.45	1.89	15.9	2.47	1.92	14.9	2.49	1.98	14.2	2.56	1.99	14.1	2.58
0:40	3.5	15.4	3.45	3.56	15.2	3.48	3.58	15.1	3.49	3.59	13.1	3.54	3.66	12.8	3.58	3.86	12.4	3.68
5:35	4.6	14.3	4.5	4.68	14.1	4.59	4.69	14	4.6	4.72	12.0	4.69	4.89	11.7	4.89	4.99	11.2	4.99
10:30	5.5	13.5	5.34	5.59	13.2	5.37	5.6	13.1	5.38	5.69	11.1	5.88	5.88	10.6	5.98	5.98	10.2	6.1
15:25	6.4	12.6	6.45	6.48	12.3	6.48	6.49	12.2	6.49	6.53	10.2	6.89	6.76	9.4	6.99	6.86	9.1	7.2
20:20	7.5	11.7	7.45	7.58	11.3	7.49	7.59	11.2	7.52	7.64	9.2	8.58	7.87	8.2	8.88	8.87	7.2	9.48
25:15	9.56	9.45	10.4	9.59	9.25	10.5	9.69	7.25	11.5	9.78	6.25	12.58	10.48	6.0	12.88	11.48	5.6	13.78
30:10	11.45	7.34	13.2	11.55	7.14	13.8	11.85	6.14	14.8	11.98	5.14	15.8	12.98	5.0	15.9	13.98	4.2	16.86
35:5	13.65	5.45	15.6	13.85	5.15	15.9	13.95	4.15	16.9	14.24	3.15	17.9	15.24	3.0	18.78	16.24	2.8	19.88
40:0	15.76	4.75	18.5	15.96	4.35	18.8	16.06	3.35	19.8	17.86	2.35	20.8	18.56	2.0	21.8	19.56	2.1	22.64

*MDD x10⁻¹ and Gs x10⁻¹

Table 4 Compaction behaviour of treated soil

4. táblázat A kezelt talajok tömörítési viselkedése

Proportion of Geopolymer to Ordinary Portland Cements (GPC/OPC)	Percentage of Crushed Waste Glasses (CWG) added (%)																	
	0%			4%			8%			12%			16%			20%		
	LL	PL	Ip	LL	PL	Ip	LL	PL	Ip	LL	PL	Ip	LL	PL	Ip	LL	PL	Ip
0:0	46	21	25	44	22	24	40	17	23	38	16	22	37	16	21	36	16	20
0:40	43	21	22	42	21	21	38	18	20	37	17	20	35	16	19	34	15	19
5:35	41	20	21	39	19	20	37	18	19	35	17	18	32	15	17	30	13	17
10:30	38	18	20	36	17	19	34	16	18	32	15	17	30	14	16	28	13	15
15:25	35	17	18	32	14	18	29	12	17	26	10	16	25	10	15	24	10	14
20:20	31	15	16	30	15	15	27	13	14	24	11	13	23	11	12	21	10	11
25:15	29	16	13	26	14	12	23	11	11	21	11	10	20	11	9	18	10	8
30:10	25	15	10	22	13	9	19	11	8	17	10	7	15	9	6	14	9	5
35:5	19	12	7	17	11	6	16	11	5	15	11	4	14	11	3	12	10	2
40:0	16	12	4	14	11	3	12	9	3	10	8	2	10	9	1	9	8	1

Table 5 Consistency behaviour of treated soil

5. táblázat A kezelés hatása a talajok konzisztenciájára

Plunger Penetration (mm)		Plunger Load (kN)									
		California bearing ratio behaviour of OPC+QDbGPC (%) treated soil with 0% CWG									
		0	0+40	5+35	10+30	20+20	25+15	30+10	35+5	40+0	
0		0	0	0	0	0	0	0	0	0	
0.5		1.2	1.5	1.8	2.1	4.4	8.4	12.4	16.5	20.5	
1		1.3	1.6	1.9	2.2	4.5	8.5	12.5	16.6	20.6	
1.5		1.5	1.7	2.0	2.3	4.6	8.6	12.6	16.7	20.7	
2		1.7	1.8	2.1	2.4	4.7	8.7	12.7	16.8	20.8	
2.5		1.8	1.9	2.2	2.5	4.8	8.8	12.8	16.9	20.9	
3		2.0	2.1	2.3	2.6	4.9	8.9	12.9	17.0	21.0	
3.5		2.1	2.2	2.4	2.7	5.0	9.0	13.0	17.1	21.1	
4		2.2	2.3	2.5	2.8	5.1	9.1	13.1	17.2	21.2	
4.5		2.3	2.4	2.6	2.9	5.2	9.2	13.2	17.3	21.3	
5		2.4	2.5	2.7	3.0	5.3	9.3	13.3	17.4	21.4	
5.5		2.6	2.7	2.8	3.1	5.4	9.4	13.4	17.5	21.5	
6		2.7	2.8	2.9	3.2	5.5	9.5	13.5	17.6	21.6	
6.5		2.9	2.9	3.0	3.3	5.6	9.6	13.6	17.7	21.7	
7		3.2	3.3	3.4	3.5	5.7	9.7	13.7	17.8	21.8	
7.5		3.6	3.7	3.8	3.7	5.8	9.8	13.8	17.9	21.9	
8		3.8	3.9	4.0	4.1	6.2	9.9	13.9	18.0	22.0	
8.5		4.1	4.2	4.3	4.4	6.5	10.0	14.0	18.1	22.1	
9		4.3	4.4	4.5	4.6	6.7	10.1	14.1	18.2	22.2	
9.5		4.4	4.5	4.6	4.7	6.8	10.2	14.2	18.3	22.3	
10		4.5	4.6	4.7	4.8	6.9	10.3	14.3	18.4	22.4	

Table 6 California bearing ratio behaviour of OPC+QDbGPC (%) treated soil with 0% CWG

6. táblázat OPC+QDbGPC-vel kezelt talaj kaliforniai teherbírási értéke (0% CWG esetén)

Fig. 5 Influences of crushed waste glasses on compaction behaviour of treated soil: (a) maximum dry density ($\times 10^{-1}$), (b) optimum moisture content, (c) specific gravity ($\times 10^{-1}$)

5. ábra Zúzott üveghulladék hatása a kezelt talajok tömörödési viselkedésén: (a) maximális száraz testsűrűség ($\times 10^{-1}$), (b) optimális nedvesség tartalom, (c) fajtsúly ($\times 10^{-1}$)

hydration of the stabilized mixture and its increased calcination and pozzolanic activity have contributed to the behaviour of the soil. And also due to molecular rearrangement in the formation of transitional compounds [2]. This improvement is due to the hydration of the highly silicate-based pozzolanic additives from the quarry dust based geopolymer cement (QDbGPC) with the treated soil matrix, which reduced the PI consistently thereby producing a stiff mixture of stabilized soil. Also, the release of more cations from the biomass based geomaterials and quarry dust during the cation exchange reaction has contributed to the behaviour of the stabilized mixture. This behaviour agrees with Little *et al.* [61], which showed that if water is used as pore fluid, the influence of the mechanical factors would remain same with a general decrease in LL and PI on addition of an admixture and binder. The prone to cracks and brittle behaviour of Portland treated soils has contributed to the improved consistency limits at reduced rates of the DOPC [2].

3.4 California bearing ratio behaviour of OPC plus QDbGPC treated soil with crushed waste glasses (CWG)

CBR test was conducted to determine the untreated and treated soils resistance to shear failure when subjected to axial loads. Traffic loads are axial dynamic loads pavement facilities

Fig. 6 Influences of crushed waste glasses on consistency behaviour of treated soil: (a) Liquid limits, (b) Plastic limit, and (c) Plasticity index

6. ábra Zúzott üveghulladék hatása a kezelt talajok konzisztenciájára: (a) Sodrasi határ, (b) Folyási határ, (c) Plasztikus index

are exposed to from vehicles of various sizes and penetration pressures. Pavements and pavement foundation fail by shear or lateral displacement (deformation). Hence it is important to observe the rigidity or stiffness of subgrade materials used as underlain structures. The CBR behaviour results of the underlain subgrade soil were presented in Tables 6-12 and Figs. 7 & 8. The studied soil was observed to be an expansive soil and was treated alternately with QDbGPC and OPC in the ratios of 0:0, 0:40, 5:35, 10:30, 15:25, 20:20, 25:15, 30:10, 35:5, and 40:0 by weight respectively. The effect of 4%, 8%, 12%, 16% and 20% by weight of crushed waste glasses over the cemented test soil was also observed. While 0:0% of the cements proportion by weight of solid served as the control point, the proportions of GPC increased from 5% in an increment of 5% while OPC decreased from 40% at the rate of 5% also. There was a consistent improvement on the CBR value of the treated soil with increased QDbGPC and reduced DOPC proportions. These improved CBR values were greater than 20%, and satisfy the material condition for use as improved subgrade material on Nigeria's dilapidated roads [7]. The consistently increased CBR values with the addition of QDbGPC was due to the presence of adequate amount of calcium required for the formation of Calcium Silicate Hydrate (CSH) and Calcium Aluminate Hydrate

Plunger Penetration (mm)	Plunger Load (kN)								
	California bearing ratio behaviour of OPC+QDbGPC (%) treated soil with 4% CWG								
	0	0+40	5+35	10+30	20+20	25+15	30+10	35+5	40+0
0	0	0	0	0	0	0	0	0	0
0.5	1.3	1.6	1.9	2.2	4.5	8.5	12.5	16.6	20.6
1	1.4	1.7	2.0	2.3	4.6	8.6	12.6	16.7	20.7
1.5	1.6	1.8	2.1	2.4	4.7	8.7	12.7	16.8	20.8
2	1.8	1.9	2.2	2.5	4.8	8.8	12.8	16.9	20.9
2.5	1.9	2.0	2.3	2.6	4.9	8.9	12.9	17.0	21.0
3	2.1	2.2	2.4	2.7	5.0	9.0	13.0	17.1	21.1
3.5	2.2	2.3	2.5	2.8	5.1	9.1	13.1	17.2	21.2
4	2.3	2.4	2.6	2.9	5.2	9.2	13.3	17.3	21.3
4.5	2.4	2.5	2.7	3.0	5.3	9.3	13.4	17.4	21.4
5	2.5	2.6	2.8	3.1	5.4	9.4	13.5	17.5	21.5
5.5	2.7	2.7	2.9	3.2	5.5	9.5	13.6	17.6	21.6
6	2.8	2.9	3.0	3.3	5.6	9.6	13.7	17.7	21.7
6.5	3.0	3.1	3.1	3.4	5.7	9.6	13.8	17.8	21.8
7	3.3	3.4	3.5	3.6	5.8	9.8	13.9	17.9	21.9
7.5	3.7	3.8	3.9	3.8	5.9	9.9	14.0	18.0	22.0
8	3.9	4.0	4.1	4.2	6.3	10.0	14.1	18.1	22.1
8.5	4.2	4.3	4.4	4.5	6.6	10.1	14.2	18.2	22.2
9	4.3	4.5	4.6	4.7	6.8	10.2	14.3	18.3	22.3
9.5	4.5	4.6	4.7	4.8	6.9	10.3	14.3	18.4	22.4
10	4.6	4.7	4.8	4.9	7.0	10.4	14.4	18.5	22.5

Table 7 California bearing ratio behaviour of OPC+QDbGPC (%) treated soil with 4% CWG
7. táblázat OPC+QDbGPC-vel kezelt talaj kaliforniai teherbírási értéke (4% CWG esetén)

Plunger Penetration (mm)	Plunger Load (kN)								
	California bearing ratio behaviour of OPC+QDbGPC (%) treated soil with 8% CWG								
	0	0+40	5+35	10+30	20+20	25+15	30+10	35+5	40+0
0	0	0	0	0	0	0	0	0	0
0.5	1.4	1.7	2.1	2.3	4.6	8.6	12.6	16.7	20.7
1	1.5	1.8	2.2	2.4	4.7	8.7	12.7	16.8	20.8
1.5	1.7	1.9	2.3	2.5	4.8	8.8	12.8	16.9	20.9
2	1.9	2.1	2.3	2.6	4.9	8.9	12.9	17.0	21.0
2.5	2.1	2.1	2.4	2.7	5.0	9.0	13.0	17.1	21.1
3	2.2	2.3	2.5	2.8	5.1	9.1	13.1	17.2	21.2
3.5	2.3	2.4	2.6	2.9	5.2	9.2	13.2	17.3	21.3
4	2.4	2.5	2.7	3.0	5.3	9.3	13.3	17.4	21.4
4.5	2.5	2.6	2.8	3.1	5.4	9.4	13.5	17.5	21.5
5	2.6	2.7	2.9	3.2	5.5	9.5	13.6	17.6	21.6
5.5	2.8	2.9	3.0	3.3	5.6	9.6	13.7	17.7	21.7
6	2.9	3.0	3.0	3.4	5.7	9.7	13.8	17.8	21.8
6.5	3.1	3.2	3.2	3.5	5.8	9.8	13.9	17.9	21.9
7	3.4	3.5	3.6	3.7	5.9	9.9	14.0	18.0	22.0
7.5	3.8	3.9	4.0	4.1	6.0	10.0	14.1	18.1	22.1
8	4.0	4.1	4.2	4.3	6.4	10.1	14.2	18.2	22.2
8.5	4.3	4.4	4.5	4.6	6.7	10.2	14.3	18.3	22.3
9	4.4	4.6	4.7	4.8	6.9	10.3	14.4	18.4	22.4
9.5	4.6	4.7	4.8	4.9	7.0	10.4	14.5	18.5	22.5
10	4.7	4.8	4.9	5.0	7.1	10.5	14.6	18.6	22.6

Table 8 California bearing ratio behaviour of OPC+QDbGPC (%) treated soil with 8% CWG
8. táblázat OPC+QDbGPC-vel kezelt talaj kaliforniai teherbírási értéke (8% CWG esetén)

Plunger Penetration (mm)	Plunger Load (kN)								
	California bearing ratio behaviour of OPC+QDbGPC (%) treated soil with 12% CWG								
	0	0+40	5+35	10+30	20+20	25+15	30+10	35+5	40+0
0	0	0	0	0	0	0	0	0	0
0.5	1.5	1.8	2.2	2.4	4.7	8.7	12.7	16.8	20.8
1	1.6	1.9	2.3	2.5	4.8	8.8	12.8	16.9	20.9
1.5	1.8	2.0	2.4	2.6	4.9	8.9	12.9	17.0	21.0
2	2.0	2.2	2.5	2.7	5.0	9.0	13.0	17.1	21.1
2.5	2.2	2.3	2.6	2.8	5.1	9.1	13.1	17.2	21.2
3	2.3	2.4	2.7	2.9	5.2	9.2	13.2	17.3	21.3
3.5	2.4	2.5	2.8	3.0	5.3	9.3	13.3	17.4	21.4
4	2.5	2.6	2.9	3.1	5.4	9.4	13.4	17.5	21.5
4.5	2.6	2.7	3.0	3.2	5.5	9.5	13.6	17.6	21.6
5	2.7	2.8	3.1	3.3	5.6	9.6	13.7	17.7	21.7
5.5	2.9	3.0	3.2	3.4	5.7	9.7	13.8	17.8	21.8
6	3.0	3.1	3.3	3.5	5.8	9.8	13.9	17.9	21.9
6.5	3.2	3.3	3.4	3.6	5.9	9.9	14.0	18.0	22.0
7	3.5	3.6	3.7	3.8	6.0	10.0	14.1	18.1	22.1
7.5	3.9	4.0	4.1	4.2	6.1	10.1	14.2	18.2	22.2
8	4.1	4.2	4.3	4.4	6.5	10.2	14.3	18.3	22.3
8.5	4.4	4.5	4.6	4.7	6.8	10.3	14.4	18.4	22.4
9	4.5	4.7	4.8	4.9	7.0	10.4	14.5	18.5	22.5
9.5	4.7	4.8	4.9	5.0	7.1	10.5	14.6	18.6	22.6
10	4.8	4.9	5.0	5.1	7.2	10.6	14.7	18.7	22.7

Table 9 California bearing ratio behaviour of OPC+QDbGPC (%) treated soil with 12% CWG
9. táblázat OPC+QDbGPC-vel kezelt talaj kaliforniai teherbírási értéke (12% CWG esetén)

Plunger Penetration (mm)	Plunger Load (kN)								
	California bearing ratio behaviour of DOPC+QDbGPC (%) treated soil with 16% CWG								
	0	0+40	5+35	10+30	20+20	25+15	30+10	35+5	40+0
0	0	0	0	0	0	0	0	0	0
0.5	1.6	1.9	2.3	2.5	4.8	8.8	12.8	16.9	20.9
1	1.7	2.1	2.4	2.6	4.9	8.9	12.9	17.0	21.0
1.5	1.9	2.2	2.5	2.7	5.0	9.0	13.0	17.1	21.1
2	2.1	2.3	2.6	2.8	5.1	9.1	13.1	17.2	21.2
2.5	2.3	2.4	2.6	2.9	5.2	9.2	13.2	17.3	21.3
3	2.4	2.5	2.8	3.0	5.3	9.3	13.3	17.4	21.4
3.5	2.5	2.6	2.9	3.1	5.4	9.4	13.4	17.5	21.5
4	2.6	2.7	3.0	3.2	5.5	9.5	13.5	17.6	21.6
4.5	2.7	2.8	3.1	3.3	5.6	9.6	13.7	17.7	21.7
5	2.8	2.9	3.2	3.4	5.7	9.7	13.8	17.8	21.8
5.5	3.0	3.1	3.3	3.5	5.8	9.8	13.9	17.9	21.9
6	3.1	3.2	3.4	3.6	5.9	9.9	14.0	18.0	22.0
6.5	3.3	3.4	3.5	3.7	6.0	10.0	14.1	18.1	22.1
7	3.6	3.7	3.8	3.9	6.1	10.1	14.2	18.2	22.2
7.5	4.0	4.1	4.2	4.3	6.2	10.2	14.3	18.3	22.3
8	4.2	4.3	4.4	4.5	6.6	10.3	14.4	18.4	22.4
8.5	4.5	4.6	4.7	4.8	6.9	10.4	14.5	18.5	22.5
9	4.6	4.7	4.9	5.0	7.0	10.5	14.6	18.6	22.6
9.5	4.8	4.9	5.0	5.1	7.2	10.6	14.7	18.7	22.7
10	4.9	5.0	5.1	5.2	7.3	10.7	14.8	18.8	22.8

Table 10 California bearing ratio behaviour of DOPC+QDbGPC (%) treated soil with 16% CWG
10. táblázat OPC+QDbGPC-vel kezelt talaj kaliforniai teherbírási értéke (16% CWG esetén)

Plunger Penetration (mm)	Plunger Load (kN)								
	California bearing ratio behaviour of OPC+QDbGPC (%) treated soil with 20% CWG								
	0	0+40	5+35	10+30	20+20	25+15	30+10	35+5	40+0
0	0	0	0	0	0	0	0	0	0
0.5	1.7	2.0	2.3	2.6	4.9	8.9	12.9	17.0	21.0
1	1.8	2.2	2.5	2.7	5.0	9.0	13.0	17.1	21.1
1.5	2.0	2.3	2.6	2.8	5.1	9.1	13.1	17.2	21.2
2	2.2	2.4	2.7	2.9	5.2	9.2	13.2	17.3	21.3
2.5	2.4	2.5	2.8	3.0	5.3	9.3	13.3	17.4	21.4
3	2.5	2.6	2.9	3.1	5.4	9.4	13.4	17.5	21.5
3.5	2.6	2.7	3.0	3.2	5.5	9.5	13.5	17.6	21.6
4	2.7	2.8	3.1	3.3	5.6	9.6	13.6	17.7	21.7
4.5	2.8	2.9	3.2	3.4	5.7	9.7	13.8	17.8	21.8
5	2.9	3.0	3.3	3.5	5.8	9.8	13.9	17.9	21.9
5.5	3.1	3.2	3.4	3.6	5.9	9.9	14.0	18.0	22.0
6	3.2	3.3	3.5	3.7	6.0	10.0	14.1	18.1	22.1
6.5	3.4	3.5	3.6	3.8	6.1	10.1	14.2	18.2	22.2
7	3.7	3.8	3.9	4.0	6.2	10.2	14.3	18.3	22.3
7.5	4.1	4.2	4.3	4.4	6.3	10.3	14.4	18.4	22.4
8	4.3	4.4	4.5	4.6	6.7	10.4	14.5	18.5	22.5
8.5	4.6	4.7	4.8	4.9	7.0	10.5	14.6	18.6	22.6
9	4.7	4.8	4.9	5.1	7.1	10.6	14.7	18.7	22.7
9.5	4.9	5.0	5.1	5.2	7.3	10.7	14.8	18.8	22.8
10	5.0	5.1	5.2	5.3	7.4	10.8	14.9	18.9	22.9

Table 11 California bearing ratio behaviour of OPC+QDbGPC (%) treated soil with 20% CWG
11. táblázat OPC+QDbGPC-vel kezelt talaj kaliforniai teherbírási értéke (20% CWG esetén)

Fig. 7 Effect of crushed waste glasses proportion on the CBR behaviour of DOPC+QDbGPC (%) treated soil
7. ábra Zúzott üveghulladék arányának hatása a DOPC+QDbGPC-vel kezelt talaj kaliforniai teherbírási értékére

CWG Proportion by wt (%)	CBR of DOPC+QDbGPC (%) treated soil with CWG								
	0	0+40	5+35	10+30	20+20	25+15	30+10	35+5	40+0
0	13	14	17	19	36	66	97	128	158
4	14	15	17	20	37	67	97	128	159
8	16	16	18	20	38	68	98	129	159
12	17	17	20	21	39	69	99	130	160
16	17	18	20	22	39	69	100	131	161
20	18	19	21	23	40	70	100	131	162

Table 12 California bearing ratio of DOPC+QDbGPC (%) treated soil with CWG
8. táblázat CWG tartalmú DOPC+QDbGPC-vel kezelt talaj kaliforniai teherbírási értéke

(CAH), which are the major compounds responsible for the formation of sequestrum, flocs and strength development [1, 2]. The soil + QDbGPC blends at 40:0% by weight cementation met the minimum requirement for CBR value of 20 – 30% specified by Dogbey and Gidigasú [60] for materials suitability for use as base course materials when determined at MDD and OMC. Increase in CBR value, was an indication of the improvement observed in MDD, which is attributed to the compatibility of the grains of soil due to the increased cations released and the high pozzolanic and silicate properties of the QDbGPC such that greater polycondensation and densification were achieved.

Fig. 8 California Bearing Ratio of DOPC+QDbGPC (%) treated soil with CWG
8. ábra CWG tartalmú DOPC+QDbGPC-vel kezelt talaj kaliforniai teherbírási értéke

5. Conclusions

The test soil treated alternately with QDbGPC and OPC in the ratios of 0:0, 0:40, 5:35, 10:30, 15:25, 20:20, 25:15, 30:10, 35:5, and 40:0% by weight respectively under the influence of 4%, 8%, 12%, 16% and 20% by weight crushed waste glasses over the cemented test soil was experimented in the lab and concluded as follows;

- The preliminary test on the natural soil showed that the test soil was an expansive problem soil of highly plastic consistency unsuitable to be used as a pavement foundation material.
- The increase in the proportion of quarry dust based geopolymer cement and reduced ordinary Portland cement proportions improved the consistency, compaction and California bearing ratio characteristics of the soil
- The addition of crushed waste glasses also improved the tested properties of the soils of consistency and strength development.

- The use of 40:0% by weight of solid of the QDbGPC and DOPC respectively produced the highest improvement of the consistency and strength development characteristics of the treated soil.
- This improvement has been achieved at zero release of CO₂ into the atmosphere (at 40:0% cementation) because the geopolymer cement is an ecofriendly geomaterials.
- Finally, the test exercise has generated a disposal mechanism for waste glasses and quarry dust as solid waste materials with an attendant improvement to soil reengineering for pavement foundation purposes in the composite blend of the silicate-based geopolymer cement.

Funding

This work was supported by the Ministry of Education and Training of Vietnam based on the decision No. 5652/QD-BGDDT on December 28, 2018 with project number B2019-MDA-08.

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Építőanyag – Journal of Silicate Based and Composite Materials, Vol. 72, No. 6 (2020), 186–197. p.
<https://doi.org/10.14382/epitoanyag-jsbcm.2020.31>

The 23rd International Conference on Composites Materials (ICCM 23) will be held in Belfast, Northern Ireland, from the 1st to 6th of August 2021. ICCM is the premier international conference in the field of composite materials and was first held in 1975 in the cities of Geneva and Boston. Since that time the conference has been held biennially in North American, European, Asian, Oceanic, and African cities.

ICCM 23 will attract the leading researchers and practitioners, to report and exchange ideas on the latest developments in the advancement and exploitation of a wide range of composites materials and structures. The general themes of material development, testing, modelling, manufacturing and design will encompass a breadth of topics which will provide a comprehensive global snap-shot of the state-of-the-art.

Plenary and keynote lectures from pre-eminent leaders in the field are planned, along with oral and poster presentations from an expected large delegation coming together in Belfast from all corners of the world. A number of site visits and an entertaining social programme are also planned.

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