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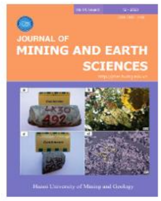

Unconfined compressive strength assessment of soil-cement mixtures in Hai Duong city

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ABSTRACT

The unconfined compressive strength (q_u) of the soil-cement mixture (S-CM) depends on many factors, in which the soil type and the cement content (%CM) are very important factors. The soil type determines the fine particle content and affects the effectiveness of soil-cement mixture. Meanwhile, %CM has a direct influence on the q_u of the S-CM. The cost of foundation treatment methods for small and medium-sized constructions depends on the reasonable cement content. This paper presents the unconfined compressive strength of S-CM for five common cohesive soils in Hai Duong city (soft clay, soft clayey sand, soft sandy clay, clayey sand mud, and sandy clay mud) with four cement contents (7%, 10%, 15%, and 20%). The research results show that the clayey sand ($mbQ_2^{1-2}hh$) has the highest improvement efficiency compared to other soils, i.e., soft sandy clay (abQ_2^3tb), soft clay ($mQ_2^{1-2}hh$), sandy clay mud ($mbQ_2^{1-2}hh$), and clayey sand mud ($amQ_2^{1-2}hh$). The clay content has a great influence on the q_u of S-CM. With the required value of $q_{u28} = (8.0 \div 10.0)$ kG/cm^2 (at 28 curing days), the reasonable cement content (% CM) is varied from 8% to 13% for soft sandy clay (abQ_2^3tb), soft clay ($mQ_2^{1-2}hh$), sandy clay mud ($mbQ_2^{1-2}hh$), and clayey sand mud ($amQ_2^{1-2}hh$); with the same value of q_{u28}, the reasonable %CM is from 7.5 to 9.0% for clayey sand ($mbQ_2^{1-2}hh$). The results are the scientific basis for recommending a reasonable %CM for each type of soil when designing to reinforce the foundation with soil-cement columns in Hai Duong city.

1. Introduction

The soil-cement column method (SCCM) is one of the most popular methods for soft soil reinforcement. When cement (CM) is mixed with soil (S), the cement acts as a binder and the soil acts as the aggregate. Soil is mixed in situ with CM to create a new material, soil-cement mixture (S-

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CM) with better mechanical properties and stability to water. The mechanical properties of the S-CM depend on many factors such as %CM, mixing technology, and soil's type (particle composition; mineral composition; organic content; easily soluble salts content; the pH of the soil), etc (Vu, 2018). Nowadays, SCCM is widely applied in the world as well as in Vietnam, be applied to many types of construction such as waterproofing trench walls for dams; reinforcing foundations and making foundations for constructions, repairing seepage-bearing culverts and culvert bottoms, stabilizing retaining walls, preventing roof slippage, reinforcing soft soil around tunnels, reinforcing roadbeds, abutments of bridges, etc. In Vietnam, this method is interesting (Do and Do, 2018) and has been standardized in TCVN 9403:2012. Accordingly, the reasonable cement content in SCCM is one of the most important factors.

Hai Duong city is a grade 1st urban area, with a total area of 111.64 km^2, which has a population of 508,190 people. It's also being expanded with dozens of new residential areas, many industrial parks, and industrial clusters, such as Factory production; Office of the People's Committee of the commune; Schools; Clinics; and Urban housing, etc., has a scale of 2 to 4 floors, accounting for 70% of the planning (Nikken Sekkei Civil Ltd., 2007). According to published research results, Hai Duong city is located in an area with a soft soil ground structure. This soft soil is mainly of sedimentary origin in the Holocene which is widely distributed on the surface and can be up to a depth of 25 m (Le, 2008). There are 5 types of soft clay in this area: soft clay; very soft sandy clay; sandy clay; sandy clayey mud and clayey sandy mud. Therefore, for the construction of the above items, the soft soil ground needs to be treated and reinforced (Le, 2008).

SCCM has been widely used in Hai Duong city. However, there is no overall research about the unconfined compressive strength of SCCM. Therefore, the paper presents the research results in the laboratory to assess the unconfined compressive strength of SCCM for five soft soils belonging to Holocene sediments distributed in Hai Duong city, as the basis for the design and evaluation of SCCM.

2. Materials and research methods

2.1. Materials

Holocene soft soils in Hai Duong City are different compositions and properties, which are widely distributed. According to the Northern Union of Engineering Geology - Hydrogeology in 1999 and the map of the soft soil structure of Hai Duong city (Pham et al., 2008), there are 5 types of soft soil. The age, origin, composition, state, and sampling locations of these soils are shown in Table 1 and Figure 1. The characteristic physicomechanical properties of each type of soft soil are shown in Table 2.

The Hai Duong PCB30 cement is used in this research. The technical characteristics of cement are shown in Table 3.

2.2. Research methods

According to the ground structure of the study area, soft soil was taken in boreholes at specific locations and depths for each soil. This sampling location is shown in Table 1.

The process of molding and curing samples is strictly carried out (TCVN 9403:2012). Accordingly, the mould used has dimensions of 7.07×7.07×7.07 cm (Figure 2).

Figure 1. Soils in the research.

Table 1. The characteristicics of soft soils.

Symbol	Age of soil	Description	Depth (m)	Thickness (m)	Sampling Location
S1	abQ_2^3*tb*	Soft, brownish yellow, sandy Clay	0÷2.0	0.5÷1.5	Thanh Binh ward, Hai Duong City
S2	mQ_2^{1-2}*hh*	Very soft – soft, bluish grey Clay	2.0÷3.5	0.5÷2.0	Thanh Binh ward, Hai Duong City
S3	mbQ_2^{1-2}*hh*	Blackish grey, clayey sandy mud, mixed seashell	3.5÷10.0	3.0÷7.0	Cam Thuong ward, Hai Duong City
S4	mbQ_2^{1-2}*hh*	Soft blackish grey, clayey Sand	7.0÷15.0	2.0÷5.0	Cam Thuong ward, Hai Duong City
S5	amQ_2^{1-2}*hh*	Blackish grey, sandy clayey mud with organic matter	15.0÷20.0	5.0÷15.0	Lien Hong commune, Hai Duong City

Table 2. Particle composition and physico-mechanical properties of soft soils.

No.	Properties		Symbol	Unit	Average				
					S1	S2	S3	S4	S5
1	Particle size	2.0÷1.0 mm	P	%	0	0	0	0	0
		1.0÷0.5 mm			0	0	0	0	0
		0.5÷0.25 mm			2	2	5	9	2
		0.25÷0.1 mm			9	8	17	21	9
		0.1÷0.05 mm			21	16	26	30	21
		0.05÷0.01 mm			32	31	30	21	31
		0.01÷0.005 mm			12	11	11	10	11
		<0.005 mm			25	33	11	9	26
2	Moisture content		W	%	32.1	30.9	36.6	21.9	53.8
3	Bulk unit weight		γ	g/cm^3	1.87	1.88	1.76	1.88	1.63
4	Dry unit weight		γ_d	g/cm^3	1.41	1.44	1.29	1.54	1.06
5	Specific density		γ_s	g/cm^3	2.69	2.70	2.67	2.66	2.65
6	Voil ratio		e_0	-	0.903	0.877	1.078	0.729	1.499
7	Porosity		n	%	47.4	46.7	51.9	42.2	60.0
8	Saturation degree		Sr	%	95.6	95.1	90.7	79.8	95.1
9	Liquid limit		LL	%	37.3	38.0	35.8	25.4	50.6
10	Plastic limit		PL	%	22.6	20.6	29.7	18.7	35.0
11	Plastic index		PI	%	14.7	17.4	6.2	6.7	15.6
12	Liquid index		LI	-	0.65	0.59	1.13	0.48	1.20
13	SPT value		N_{30}	blows	4	2	6	9	2

Table 3. The properties of cement.

No.	Properties		Value
1	Compressive strength, N/mm^2	3 days	18
		7 days	40
2	Freezing time	Start (hour)	3
		End (hour)	8
3	Fineness (remaining on 0.08mm sieve) (%)		8.6
4	Volumetric Corrosion (mm)		6.7
5	SO_3 content (%)		1.2

Figure 2. The mold.

The soil is wind-dried, crushed, and passed through sieve Φ5 (Figure 3). In order to mix cement-soil-water into a homogeneous mixture with the design ratio, the weight of soil, and the moisture of soil; cement, and water are determined (TCVN 9403: 2012). The soil is mixed with the cement in the mixer tank for 10 minutes with a ratio of 7%; 10%; 15%; and 20%. Where the amount of cement is calculated by the formula (1), the amount of water is calculated by the formula (2):

$$W_c = \frac{1+w}{1+w_0} a_w W_0 \quad (1)$$

$$W_w = \left(\frac{w-w_0}{1+w} + \mu a_w\right) \frac{1+w}{1+w_0} W_0 \quad (2)$$

Where: W_0 - weight of dry soil (kg); W_c - weight of cement (kg); W_w - weight of water (kg); w - water content of the soil; w_0 - water content of the dried soil; a_w - mixing ratio of cement; μ - water-cement ratio.

After that, the mixtures are put into the mold into 3 layers and compacted to ensure homogenous samples. Then, the mixture is pressed for 7 minutes until the water drained onto the plate surface. A group of 3 samples is mixed for each cement ratio. Samples are prepared with speculation of bulk unit weight (more than ± 0.05 g/cm^3). Next, the samples are left in the mold and stored (temperature 27^{0}C, 95% humidity) within 3 days. Then, the sample mold is removed and cured at 7, 14, 28 and 90 days old.

At the expected time points, the sample is taken out and drained, determined by bulk unit (γ). Then, the compressive strength (q_u) of the samples is determined. The Marshall compressor is used in this research (Figure 4). The stroke of this machine shall be such that, when the intended breaking load of the test specimen is reached, not less than 20% and not more than 80% of the total stroke. The relative error of this machine is not more than 2%.

Testing: the sample is tested immediately after being removed from the curing. The sample

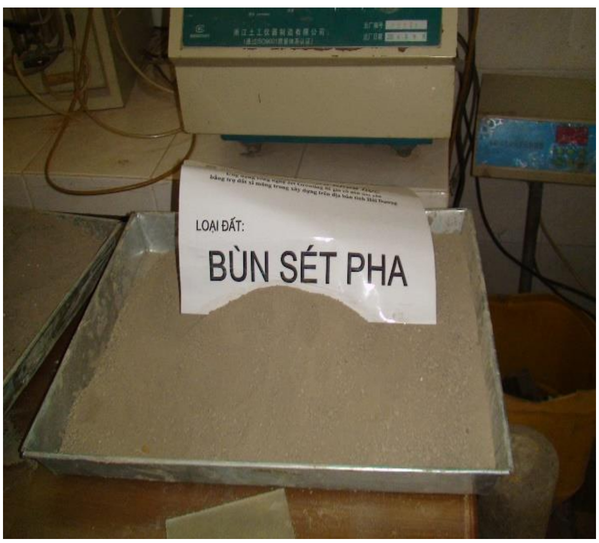

Figure 3. Prepared soil.

Figure 4. Putting sample into the compressor.

Figure 5. The sample after testing.

is placed in the center of the lower pressure table of the compressor. When the upper compression table is in close contact with the sample, adjust the spherical base to make contact evenly. The loading speed is a rate of (10÷15) N/s (or h (1÷2) mm/min). When the sample has rapid deformation, the compressor head valve stops. When the sample is damaged, the maximum load is recorded.

The compressive strength of the sample is calculated:

$$q_u = \frac{P}{A}\mathrm{A} \qquad (3)$$

Where: q_u - compressive strength of S-CM, kG/cm^2; P - maximum load, kG; A - compressive sample area, cm^2.

When the result of the test sample exceeds 15% of the average value of the group, only the values of the remaining 2 samples are taken.

3. Results and discussion

Five typical soft soils in Hai Duong were tested with 4 cement proportions (7%; 10%; 15% and 20%) and determined the compressive strength at 4 times of age (at 7, 14, 28, and 90 days). Thus, there was a total of 240 samples. The results are summarized in Table 4.

From the results research, the relationships between q_u and %CM for each type of soil are analyzed as shown in Figures 6, 7, 8, 9, and 10.

According to the graphs (Figures 6 to 10), the resulting research shows that q_u increases with age and cement content. In which, q_u of all mixed samples increased rapidly in the first period from 7 to 28 days of age, then the increasing degree decreased. The data from Table 3 shows that all samples of S-CM have q_u at 28 curing days (q_{u28}) equal to (72÷80)% of q_u at 90 curing days (q_{u90}). Therefore, q_{u28} can be used for preliminary assessment of the strength of the post-reinforced composite.

The relationship between q_{u28} and %CM is shown in Figure 11. The graph shows the q_{u28} development level of the cement mixture with soil types S1, S2, S3, and S5 and they tend to increase rapidly at %CM = (7÷10)%. This result shows that the soil is suitable for the cement reinforcement method. With soil S4, the relationship between q_{u28} and %CM increases almost linearly in the range %CM = (7÷20)%. The results also show that the S4 reinforcement efficiency is the highest among the 5 types. When %CM = 7%, q_{u28} value of S4 reached 7.39 kG/cm^2, and when %CM = 20%, q_{u28} value reached 24.65 kG/cm^2 at 28 days of age. This is explained by the low clay content of S4. Figure 12 shows the relationship between

Table 4. Summary of test results to determine 1-axis compressive strength (q_u).

Type of soil	%CM	7%				10%				15%				20%			
	Curing age	R7	R14	R28	R90	R7	R14	R28	R90	R7	R14	R28	R90	R7	R14	R28	R90
S1	γ (g/cm^3)	1.80	1.79	1.81	1.80	1.86	1.83	1.84	1.87	1.89	1.86	1.92	1.91	1.98	1.97	1.95	1.94
	q_u (kG/cm^2)	4.01	5.39	6.78	9.40	5.85	8.16	10.01	13.25	7.24	9.86	13.56	17.72	9.55	13.56	16.79	22.03
S2	γ (g/cm^3)	1.76	1.75	1.77	1.77	1.75	1.83	1.84	1.82	1.87	1.80	1.84	1.84	1.87	1.90	1.92	1.91
	q_u (kG/cm^2)	3.54	4.78	6.16	8.16	4.93	7.09	8.93	11.71	6.62	9.63	12.32	16.33	8.47	11.71	15.25	19.41
S3	γ (g/cm^3)	1.79	1.78	1.79	1.78	1.79	1.81	1.79	1.80	1.88	1.86	1.87	1.87	1.93	1.94	1.96	1.94
	q_u (kG/cm^2)	3.54	4.93	6.16	8.01	5.39	7.09	9.40	12.32	7.55	10.48	13.09	17.72	9.55	12.25	16.33	22.18
S4	γ (g/cm^3)	1.85	1.86	1.89	1.85	2.01	2.02	2.01	2.01	2.16	2.11	2.13	2.14	2.21	2.21	2.21	2.23
	q_u (kG/cm^2)	4.31	5.47	7.39	10.01	6.78	9.40	11.40	15.10	10.01	13.25	18.79	24.34	14.33	20.18	24.65	32.66
S5	γ (g/cm^3)	1.76	1.73	1.73	1.78	1.79	1.77	1.79	1.80	1.88	1.83	1.82	1.87	1.87	1.94	1.84	1.94
	q_u (kG/cm^2)	2.62	3.77	4.70	6.16	4.70	6.32	8.01	9.40	6.32	8.93	11.40	14.17	8.63	11.25	13.71	18.02

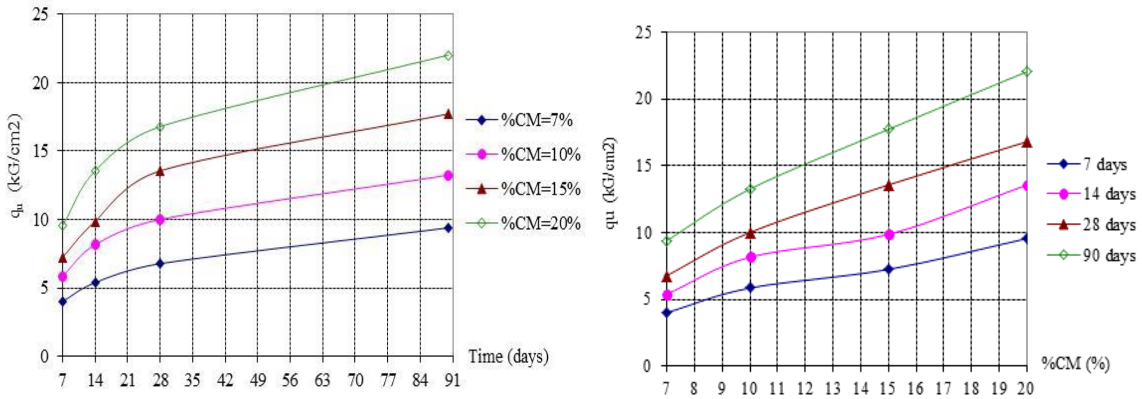

Figure 6. The compressive strength (q_u) of sample following curing time and %CM of S1 (clayey sand).

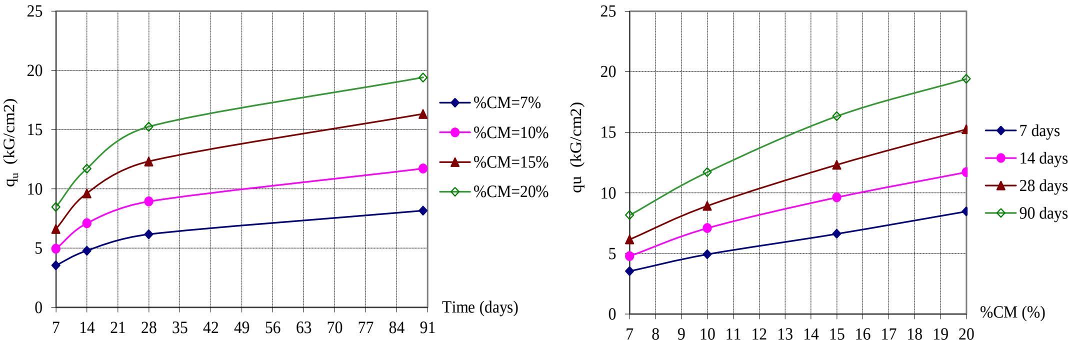

Figure 7. The compressive strength (q_u) of sample following curing time and %CM of S2 (clay).

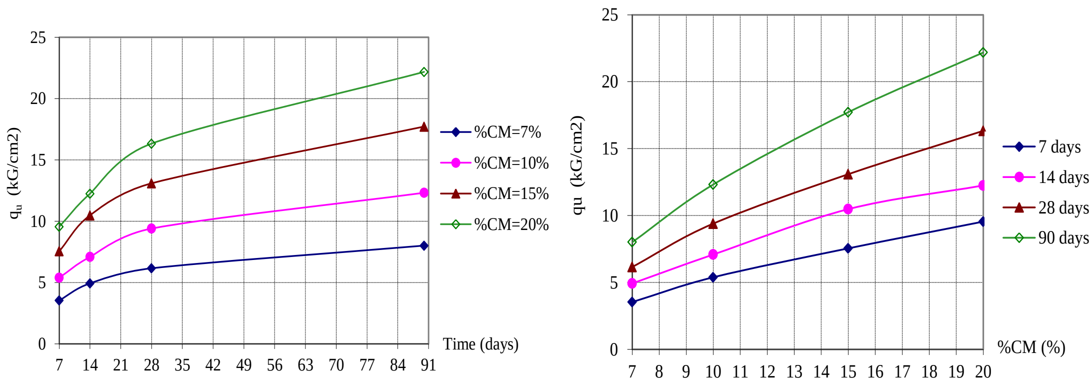

Figure 8. The compressive strength (q_u) of sample following curing time and %CM of S3 (Sandy clay mud).

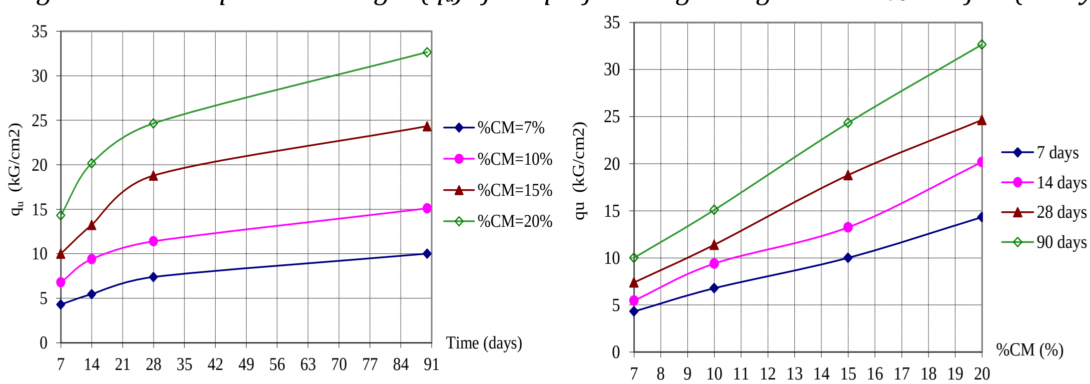

Figure 9. The compressive strength (q_u) of sample following curing time and %CM of S4 (Sandy clay).

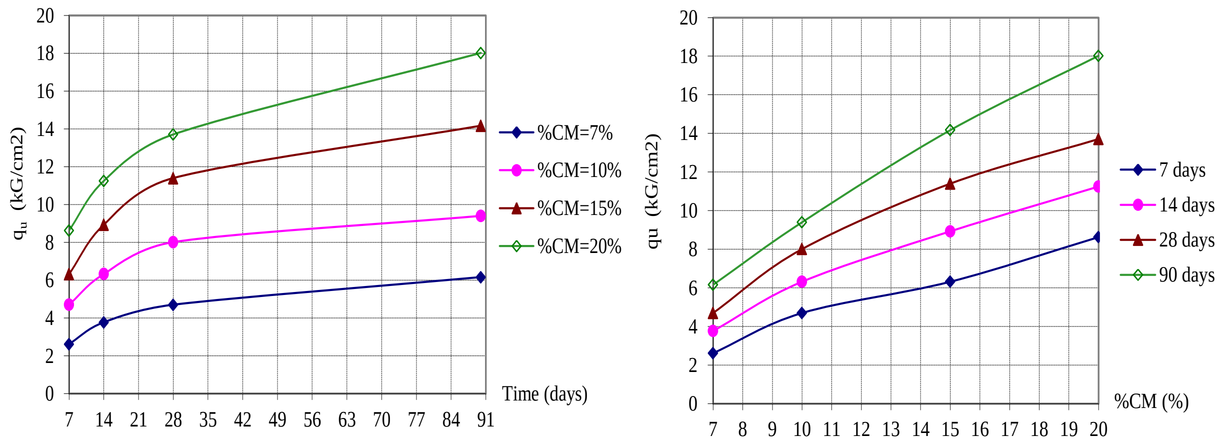

Figure 10. The compressive strength (q_u) of sample following curing time and %CM of S5 (Clayey sand mud).

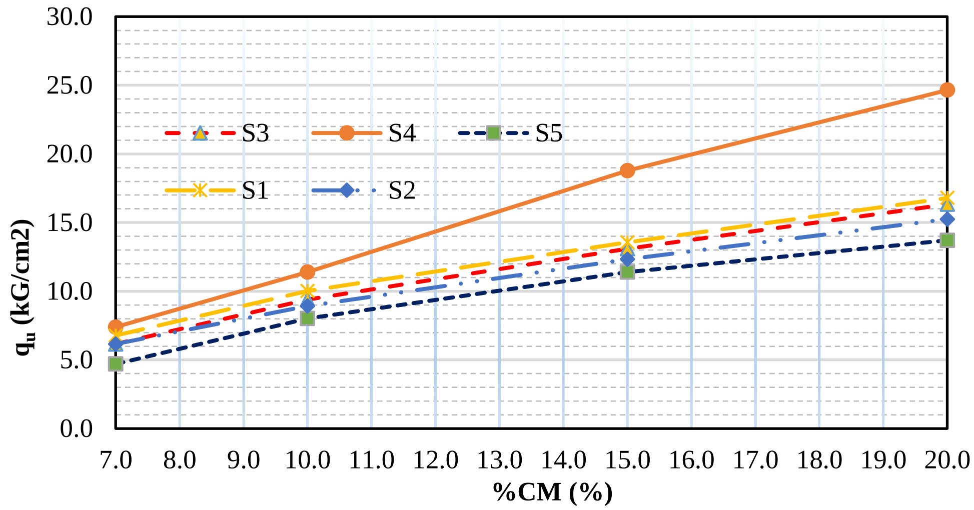

Figure 11. Relationship between q_u and %CM at 28 days.

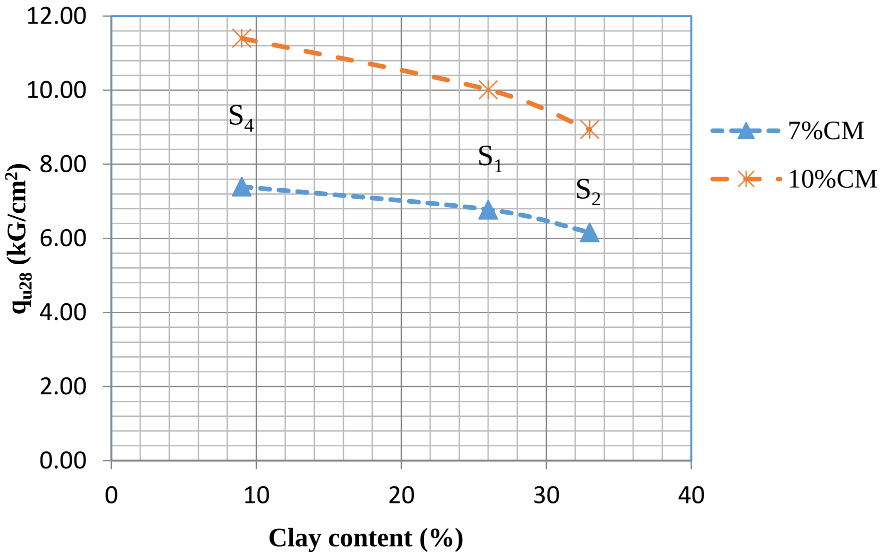

Figure 12. Relationship between q_{u28} and clay content.

Table 5. The reasonable cement content following requiring compressive strength (q_{u28}).

Type of soil	The reasonable %CM following requiring compressive strength at 28 curing days (%)	
	q_{u28} = 8.0(kG/cm^2)	q_{u28} = 10.0 (kG/cm^2)
S1	8	10
S2	9	11.5
S3	9	11
S4	7.5	9
S5	10	13

q_{u28} and clay content (S4, S1, and S2), whereby q_{u28} increases when the clay content decreases. S3 and S5 containing organic content need further research attention.

The determination of the reasonable %CM for each type of soil can be based on the required q_{u28}. For small and medium-sized constructions (from 2 to 4 floors) in Hai Duong, the required q_{u28} value is usually in the range of (8÷10) kG/cm^2. Table 5 shows reasonable cement content when required values q_{u28} = 8.0 kG/cm^2 and 10 kG/cm^2.

4. Conclusions

From the research results, the compressive strength (q_u) of S-CM is varied depending on the type of soft soil and %CM:

- The value of q_u decreases with increasing clay content, and at the same clay content, q_u increases with %CM. At the required value of q_{u28} is (8.0÷10.0) kG/cm^2, the %CM equal (8÷13)% for S1, S2, S3, and S5; and %CM is (7.5÷9)% for S4.
- The clay content significantly affects q_u. In addition, q_u is also affected by the organic content and pH of the soil and needs further research.

The research results are the scientific basis for recommending a reasonable %CM for each type of soil when designing to reinforce the foundation with soil-cement columns in Hai Duong city.

Contribution of authors

Thang Hong Do - proposes ideas and contributes to the manuscript; Phong Van Nguyen and Hung Van Nguyen - manuscript writing and contribute to the material analyses.

References

Do, M. T., Do, M. N. (2018). Motorway on soft ground. Lectures for the Graduate School of Bridge and Road, University of Transport Technology, Hanoi.

Le, H. Q. (2008). Dividing the types of ground structures in Hai Duong city and proposing appropriate foundation solutions for civil and industrial constructions. *Master thesis.* (In Vietnamese).

Nikken Sekkei Civil Ltd (2017). The project to adjust the general planning of Hai Duong city to 2030, with a vision to 2050.

Nguyen, N. T., Bui, S. T., & Van Pham, H. (2020). Utilisation of ground granulated blast furnace slag (GGBFS) for soft soil improvement by deep mixing method. *Journal of Mining and Earth Sciences Vol*, *61*(1), 92-100.

Nguyen, U. (2013). Soft ground treatment in construction. *Construction Publishing House.*

Pham, V. H., Nguyen, D. C., Le, H. C., Lai, D. H., Vu, Q. L., Nguyen, V. P., Mai, V. T., Nguyen, D. N. (2008). Monograph on Geology and Mineral Resources of Hai Duong Province. *Hai Duong Newspaper Printing Factory, Hai Duong.*

TCVN 9403: 2012 - Reinforcing soft ground - Method of soil-cement columns.

Vu, N. B. (2018). Research on the influence of construction properties of soft clay soils in the Mekong Delta on the quality of foundation reinforcement by cement combined with additives in building construction. Technical doctoral thesis. Hanoi (in Vietnamese).