Experimental Investigation on Geotechnical Characterization of Organic clay soil and its stabilization using Cement and Nano silica Additives

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Abstract: Organic soils containing low to moderate organic matter are commonly found in several regions of Kerala. Such soils are highly compressible, possess low shear strength, and exhibit poor load-bearing capacity, making them unsuitable for supporting structural loads without improvement. The presence of organic matter increases water-holding capacity, resulting in high plasticity and reduced cohesion. With rapid urbanisation, industrial growth, and increasing population, the demand for civil infrastructure has risen significantly, necessitating the use of marginal soils. While soils with very high organic content are generally avoided for construction, those with low to moderate organic matter can be improved through proper characterisation and stabilisation techniques.

The present study focuses on evaluating the geotechnical behaviour of organic clay soils with low to moderate organic content and enhancing their engineering properties using chemical stabilisation methods. Initially, a comprehensive experimental programme was carried out to assess the influence of organic content and type of organic matter on soil properties, including consistency limits, compaction characteristics, consolidation behaviour, and shear strength. Inorganic clay was collected from Pantheerankavu near Calicut, along with commercially available sodium bentonite and kaolinite, representing different clay mineralogical compositions. Organic clay soils were artificially prepared by adding starch-based organic matter in proportions ranging from 2% to 15%. Naturally occurring organic soils containing decomposed wood fibres were also examined for comparison, with organic contents between 5% and 12%. Additionally, the effects of different organic matter types—starch, urea, and compost—were investigated.

Results indicated that increasing organic content significantly alters soil behaviour, shifting plasticity from medium to high. Maximum dry density decreased while optimum moisture content increased due to enhanced water retention and soil particle disintegration. Compressibility increased markedly, leading to higher consolidation settlements, while unconfined compressive strength and shear strength decreased substantially with organic content. Strength stabilisation was observed after 28 days of curing. The influence of organic matter was more pronounced in bentonite and kaolinite-rich soils compared to illitic clays. Among organic additives, starch-based soils showed relatively lower compressibility and higher strength.

To improve soil performance, eco-friendly stabilisation using cement, nano-silica, and their combination (1% dosage) was adopted. The combined cement–nano-silica treatment provided superior strength enhancement due to accelerated pozzolanic reactions.

KEYWORDS : Load-bearing capacity, consistency limits, compaction characteristics, consolidation behaviour, and shear strength. Inorganic clay

I. INTRODUCTIONS

Organic soils contain a certain percentage of organic matter. Organic matter is the organic component in the soil derived primarily from decayed plant and animal residues at various stages of decomposition. It also consists of cells and tissues of soil organisms and substances synthesized by soil organisms. In other words, organic matter contains carbon compounds derived from dead forms (mostly dead plants), living parts of plants(roots), and living microbes and soil organisms. Dead plants constitute a significant part of organic matter. Living organisms are composed of organic compounds. In their life cycle, they secrete or excrete organic materials into their environment, shed body parts such as leaves and roots. After the organism dies, its body is broken down by bacterial and fungal action. Larger molecules of organic matter can be formed from the polymerization of different parts of already broken-down matter. The composition of natural organic matter depends on its origin, transformation mode, age, and existing environment; thus, its bio-physicochemical functions vary with different environments. organic soil formation, the topsoil is formed as plant life dies and becomes fixed with surficial soils. The organic layer's thickness and characteristics are a function of climate and drainage, and the latter is related to slope and soil type. Root mat forms in marshy regions and is a hick accumulation of living and dead marshy growth. Peat is fibrous material with a sponge-like structure, composed almost entirely of dead organic matter. Organic layers can be found in surface deposits also. It can be found deeply buried by alluvium, colluvium, beach deposits, thereby creating a zone of weakness in the strong formations. The decomposition of organic matter takes place only when the conditions are suitable. The rate of breakdown depends on the type of organic matter and the conditions in the soil. Some may be rapidly decomposing, while some may take years to decompose. The

Over the last few years, studies on organic soils with the different organic matter have focused on the characterisation and stabilisation of soils from the geotechnical engineering perspective. These organic soils can cause geotechnical complications in soil degradation, water absorption, consolidation settlement, shear strength reduction, etc. Geotechnical engineers may have experienced difficulties in handling organic soils used to support the foundation structures because of their unusual engineering properties. The usual practice is avoiding or replacing high organic content soils with good engineering soils before constructing the civil infrastructures. However, if the soil deposit contains low to medium organic matter, it is necessary to modify the geotechnical properties of organic soils. Push (1973) stated that even low organic content of about 3 to 4 % could cause a significant effect on the geotechnical properties of soils. Recent investigation studies on soils with low organic content have also noticed the same findings (Bujang et al. 2014; Al-Ravi et al. 2017, Masi et al., 2020). Research studies are also limited to understand the effect of organic content, and it has not received a unique conclusion on the characterisation of organic clay soils.

Organic content is a significant parameter that helps in classifying organic soils or peat. The methods to find the organic content are generally divided into two sections of direct and indirect methods: (i) direct methods include the loss on ignition and hydrogen peroxide methods, and (ii) indirect method includes dichromate oxidation and wet/dry combustion. The extraction of organic matter can be done by NaOH, mild extractants, organic chelates and formic acid. The most commonly used method is the loss on ignition method, i.e. heating the soil in a muffle furnace of about 350 to 440° C and calculating the organic matter content by changing weight before and after heating. However, this method overestimates the value by losing structural water and the decomposition of inorganic carbonates. Nowadays hydrogen peroxide method is also preferred since organic content can be removed from the soil without affecting the clay mineral fraction of the soil (Schmidt 1965, Mikutta et al., 2005; Reddy et al., 2014). The concentration of 30% or 50% hydrogen peroxide is used for the test, and the oxidation process removes organic matter.

- To study the effect of low to medium organic content on the geotechnical characterisation of artificially processed and naturally occurred organic clay soils.
- To investigate the effect of organic matter on geotechnical properties of naturally occurring inorganic clay soil.
- To study the influence of the curing period on the sustainability of consistency To examine the effect of cement, nano-silica, and a combination of cement and Nano-silica stabilisation methods on improving the geotechnical properties of inorganic and organic clay soils.

  To investigate the physiochemical interactions of untreated and treated organic clay soils in supporting the geotechnical characterisation of soils

II. METHODS AND EXPERIMENTAL PROGRAMME

This chapter discusses the details on the materials used in the present investigation and processing of soil mixtures with specimen preparation. The index and engineering properties of parent clay soils, including particle size distribution, Atterberg's limits, compaction and unconfined compressive strength, have determined through laboratory tests as per the relevant Indian standards. It also explained the detailing of materials used for the organic soil characterisation and stabilisation with primary properties. The methodology adopted to carry out the experimental programme of the present study has explored at the end of the chapter.

Bentonite clay: Bentonite is a highly expansive type of clay procured from the rubber chemicals plant at the Calicut district of Kerala state. It exhibits low shrinkage water content and more swelling that indicates highly expansive due to the presence of montmorillonite mineral. Table 3.1 shows the primary and strength properties of bentonite clay.

Kaolinite clay: Kaolinite is a commercial white clay that is having kaolinite mineral and low cation exchange capacity. It is soft, earthy and white. It is procured from Sajeev and Co. Ltd. At the Calicut district of Kerala state. The primary and strength properties of kaolinite clay are listed in Table 3.1

Natural clay: The natural clay has collected at a depth of 3 m from the Pantheerankavu field site, which is 12 km away from the south of Calicut city in Kerala. The soil was air-dried, pulverized manually and sieved through a 425μm sieve. The soil passing through a 425μm sieve has preserved for the present study. Fig. 3.1 shows the photographs on inorganic clay soils collected for the present study. Fig. 3.2 shows the gradation curve of natural clay. It contains 5% gravel, 25% sand, 28% silt, and 42% clay size particles. The basic and strength properties of natural clay soil have listed in Table 3.1.

Table 1: Basic and strength properties of collected inorganic soils

Properties	**Testing soils**			**IS code followed**
	Bentonite	**Kaolinite**	**Natural clay**	
Clay (%)	100	100	42	IS:2720-part 4 (1975)
Liquid limit (%)	424	36	64	IS:2720-part 5 (1985)
Plastic limit (%)	82	27	29	IS:2720-part 5 (1985)
Shrinkage limit (%)	5	24	16	IS:2720-part 6 (1972)
Plasticity Index (%)	342	9	35	-
Cu	1	1	5.2	-
Cc	1	1	1	-
Soil classification	CH	MI	CH	IS:1498 (1970)
Specific Gravity	2.29	2.43	2.63	IS:2720-part 3 (1980)
MDD (kN/m^3)	13.6	15.8	14.4	IS:2720-part 7 (1983)
OMC (%)	39	29	37	IS:2720-part 7 (1983)
UCS (kPa)	88	175	80	IS:2720-part 10 (1991)

Three different types of organic materials, including urea, starch, and compost, are used in the present study to process the artificial organic clay soils. It intended to study the effect of organic content and type of organic matter on geotechnical properties of inorganic soils. Urea is the waste by-product of many living organisms and a major organic component of human urine. Urea is a commonly used fertiliser in the agricultural background. Ureautilising for the present study has procured from Chemind chemicals, Calicut city in Kerala. Table 3.2 presents the basic properties of urea collected from the manufacturer manual.

Table 2: Basic properties of Urea organic material (manufacturer manual)

Chemical Formulae	NH_2CONH_2
Appearance	White powder
Melting range	131-134^{o}C
Sulphated ash	0.1%
Chloride	0.002%
Sulphate	0.05%
Lead	0.002%

The present study used the starch (soluble GR grade) procured from Chemind chemicals, Calicut city in Kerala. Starch, a non-humus organic substance, is generally a rapidly decomposing material. On the other hand, it is a coarser organic chemical produced by all green plants. Chemically a glucose polymer and is first hydrolysed to maltose by the action of amylases. The nature of compost is complex humus-like organic matter. Compost has a high cation exchange capacity and can increase the CEC of soil when added to it. The essential nutrients in compost are organic forms that are released slowly. The sponge-textured humus-like substance in the compost facilitates aggregates (Mylavarapua 2009), and the effect of compost on aggregate stability depends on soil. The present study used locally available vermin compost.

Naturally occurred organic soils with decomposed wood fibre, i.e. starch type of organic matter procured nearby mills containing the organic content in the range of 4.7% to 12% by weight of soil. Since both the naturally occurred and artificially processed organic soils have a similar type of organic starch compound, it is easy to compare the effects of organic content on the strength properties of inorganic clay soil. Organic content presents in the naturally occurred soil is determined by using a loss of ignition method. It contains about 45% of silt and 42% of clay size particles.

Nano-silica: Nano-silica used for the present investigation was procured from Astra Chemicals Chennai. Nano chemical stabilisation is one of the modern developed techniques in which nano-silica is most widely used as an additive to stabilise the clayey soils because of its micro and nano filling property, high pozzolanic reactivity and controlled crystallisation process.

Cement: Locally available Portland pozzolana cement has been used in the present study to stabilise the clay soils at low dosages. It acts as an accelerating binding agent on nano- silica stabilisation of soils. The cementation reaction and pozzolanic activity of the nano- silica accelerated in the presence of even a small amount of cement.

III. RESULTS AND DISCUSSION

This chapter presents the results and discussions on the geotechnical characterisation of organic clay soils, including stabilising both the inorganic and organic clay soils. A few organic clay soils were collected from the field site in its natural state, containing decomposed wood with carbohydrates. Some other organic clay soil mixtures were artificially processed after adding commercially available organic matter at low to medium proportions into the inorganic clay soils. Initially, test results discuss the effects of organic content and type of organic matter on various strength properties of clay soil. Later, it extends to study the stabilisation of both the inorganic and organic clay soils and the effect of the stabilisation method.

It comprises to study the effect of organic content on geotechnical properties of inorganic clay in both the naturally occurred organic soils and artificially processed organic soils. Naturally occurred organic soils were procured nearby mills that contain the organic content in the range of 4.7% to 12% by weight of soil. On the other hand, artificially processed organic soils contain commercially available starch in the range of 5% to 15% by the weight of inorganic clay soil. Since both the naturally occurred and artificially

A. *Consistency Limits*

A series of Atterberg's limit tests were conducted on different organic clay soil mixtures containing organic content in the range of 2 to 15%. Tables 4.1 to 4.3 show the experimental results on variation of liquid limit, plastic limit, and shrinkage limits with organic content added to the different clay soils. The consistency limits of liquid and plastic limits and their numerical differences increase with an increase in the organic content irrespective of the type of clay soils. Shrinkage limits are decreasing with the rise of organic content in the clay soils. It indicates the soil mixtures become more expansive with a broader range of water contents while increasing the organic content.

Table 3: Influence of organic content on consistency limits of bentonite inorganic clay

OC, %	Consistency limits, %				% increase of			% decrease of
	w_l	w_p	w_s	I_p	w_l	w_p	I_p	w_s
0	424	82	5	342	--	--	--	--
2	435	88	5	347	2.6	7.3	1.5	0
5	477	92	4.8	385	12.5	12.2	12.6	4
10	511	102	4.5	409	20.5	24.4	19.6	10
15	535	107	4.1	428	26.2	30.5	25.2	18

Table 4: Influence of organic content on consistency limits of kaolinite inorganic clay

OC, %	Consistency limits, %				% increase of			% decrease of
	w_l	w_p	w_s	I_p	w_l	w_p	I_p	w_s
0	36	27	25	9	--	--	--	--
2	36	27	25	9	0	0	0	0
5	39	29	24	10	8.3	7.4	11	4.0
10	46	33	22	13	27.7	22.2	44	12
15	51	35	20	16	41.7	29.6	77.7	20

Table 5: Influence of organic content on consistency limits of natural inorganic clay

OC, %	Consistency limits, %				% increase of			% decrease of
	w_l	w_p	w_s	I_p	w_l	w_p	I_p	w_s
0	64	29	16	35	--	--	--	--
2	70	31	15	39	9.4	6.8	11.4	6.2
5	77	33	14	44	20.3	13.8	25.7	12.5
10	82	36	13	46	28.1	24.1	31.4	18.8
15	89	41	12	48	39.0	41.3	37.1	25

B. Compaction behaviour & Unconfined Compression Strength

variation of compaction properties in organic soil mixtures with an increase in the organic content in the range of 2 to 15%. Results are indicating that the optimum moisture content is increasing with an increase in the organic content. It might be due to increased water absorption by the organic content and change of plasticity limits. The maximum dry density corresponding to OMC decreases with an increase in the organic content presented in the soil mixtures. It demonstrates that the soil mixture become lighter due to the disintegration of soil particles in the presence of organic matter. It is observed that the increase in OMC is about 30-32%, and the decrease in maximum dry density is about 5-7%, with an increase in the organic content up to 15% into the organic soil mixtures. There is a negligible effect on compaction properties with low organic content of about 2% in the clay soils. In the second phase, the present study was extended to examine the influence of organic content on the geotechnical properties of naturally occurring organic soils compared with artificially processed organic soil mixtures. Naturally occurring organic soils were procured from nearby mills that contain organic content in the range of 4.7% to 12% by weight of soil. These soils have organic matter in the form of decomposed wood with carbohydrates. Organic content presents in the naturally occurring soil is determined by using the loss of ignition method. It contains about 45% of silt and 42% of clay particles.

Table 6: Effect of organic content on compaction properties of organic soil mixtures

OC, %	Bentonite organic soil mixture		Kaolinite organic soil mixture		Natural clay organic soil mixture	
	OMC, %	MDD, kN/m^3	OMC, %	MDD, kN/m^3	OMC, %	MDD, kN/m^3
2	41	13.6	27	15.4	31	14.1
5	44	13.4	28	15	33	13.9
10	49	13.2	31	14.7	37	13.6
15	53	12.9	35	14.3	41	13.3

Table 7: Strength properties of naturally occurred organic soils

Soil	OC, %	Compaction parameters		Unconfined Compression Strength, kPa
		MDD, g/cm^3	OMC, %	
1	4.7	1.82	23	135
2	5.4	1.85	27	128
3	7.1	1.73	29	113
4	9.3	1.67	31	104
5	12	1.69	39	91

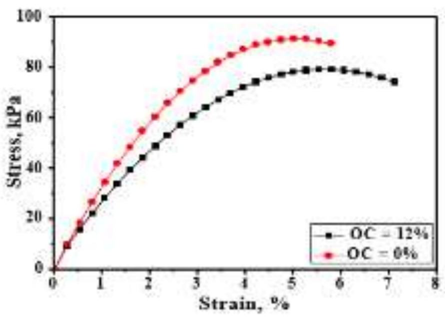

Fig 1: Stress strain variation on inorganic clay and organic soil with 12% OC under unconfined compression strength testing

C. Consistency limits and compaction parameters

A series of consistency limits and standard proctor compaction tests were conducted on organic clay soils treated with cement stabilisation. Cement additive introduced into the organic soils is 1% by weight of soil. Consistency limits and compaction strength parameters of organic soils stabilised with cement were determined from the experimental data. compares the consistency limits and compaction parameters of untreated and cement treated organic clay soils. found that liquid limits are decreasing, and plastic limits increase for the cement-treated organic clay soils compared to untreated organic clay soils irrespective of organic content presented in the soil.However, plasticity indices are significantly reduced in the stabilised organic clay soils, indicating the organic clay soil changes from high plastic to medium plastic state with cement stabilisation. For example, reducing the plasticity index of cement-treated organic clay with 15% OC is about 37.5% above the PI of untreated organic clay with 15% organic content.

Table 8: Consistency limits of untreated and cement treated organic clay soils

OC, %	**Untreated organic clay soils**			**Cement treated organic clay soils**		
	w_l**,%**	w_p **, %**	I_p	w_l**, %**	w_p **, %**	I_p
2	70	31	39	62	35	27
5	77	33	44	68	39	29
10	82	36	46	73	44	29
15	89	41	48	77	47	30

Table 9: Compaction parameters of untreated and cement treated organic clay soils

OC, %	**Untreated organic clay soils**		**Cement treated organic clay soils**	
	OMC, %	**MDD, kN/m^3**	**OMC, %**	**MDD, kN/m^3**
2	31	14.1	32	13.5
5	33	13.9	35	13.2
10	37	13.6	40	12.8
15	41	13.3	43	12.5

slight increase of OMC and decrease of maximum dry density for the cement-treated organic clay soils compared to untreated organic clay soils irrespective of organic content presented in the soil.

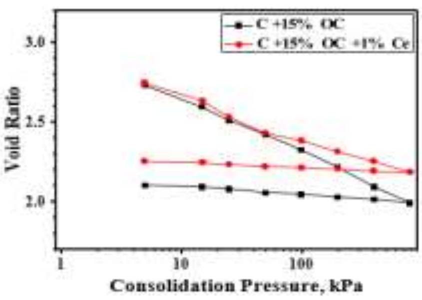

Fig 2: Loading and unloading behaviour of untreated and cement treated organic clay soils with 15% organic content

IV. CONCLUSION

The present investigation has been carried out a series of experimental tests including index and basic properties, compaction and oedometric consolidation, unconfined and CU triaxial compression tests on untreated, and stabilised inorganic and organic clay soils. The study is mainly focused on characterising the inorganic clay soils and examining the influence of organic content and type of organic matter on the geotechnical properties of organic clay soils. Further, stabilisation methods for improving the strength parameters of both the inorganic and organic clay soils are investigated. The organic clay soils were artificially processed after introducing the starch type of organic substance into bentonite, kaolinite and natural clay soils. Organic content added into the clay soil is varying from 5 to 15%. Starch, compost and urea types of organic substances are used in the present study to investigate the effect of organic matter on the geotechnical properties of soils. Effect of curing on consistency limits and strength properties of organic clay soils is studied. It is also investigated the efficiency of removing organic content from naturally occurring organic clay soils using the hydrogen peroxide method. After removing organic content, the soils showed a significant improvement in strength properties with less compressibility. The stabilisation methods, including cement, Nano silica, and cement and Nano silica, are investigated to improve the geotechnical properties of clay soils. All the stabilised soils are cured up to 28 days before conducting the tests. The significant findings arrived from the present investigation are given below

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