

# Stabilization of Marine Clay Soil Using Polyurethane

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**Abstract.** Many chemicals stabilisation techniques are being employed all over the world to improve the engineering and physical properties of the problematic soils and reduce the potential damages caused by them. Out of those chemical stabilisation technics, application of Polyurethane to improve the strength of marine clay was investigated in the laboratory. Characterization of the soil geotechnical properties was carried out by conducting laboratory test that includes natural moisture content, Atterberg limits, grains sizes analyses, specific gravity, moisture-density relationship, unconfined compressive strength (UCS), organic matter content and PH tests. Unconfined compressive strength test at optimum moisture content with varying the dose of the Polyurethane content was conducted to test the effectiveness of Polyurethane as a chemical stabiliser. The result of the preliminary tests of the sample shows that the soil has a liquid limit of 65%, plastic limit of 26% and plasticity index of 53%. The percentages of gravel, sand and fines in the marine clay sample were 0 %, 1.32 % and 98.68 % respectively %. The results of the UCS test also revealed that Polyurethane stabilisation improved the strength of marine clay by 230%. Thus, the improvement in strength of stabilised marine clay soil can significantly reduce the overall thickness of the pavement and total cost of the road construction in future.

**Keywords:** Marine clay; Polyurethane; Strength improvement and Unconfined compressive strength

## 1. Introduction

The continuous increases in population called for infrastructural development in the coastal areas which has a lot of marine clay deposit. Although constructing these infrastructures needs a good foundation soil; however, marine clay is not suitable for that purpose. It is characterised by significant swelling and shrinkage when exposed to variations in moisture content. It also has the low bearing capacity and reduced permeability. Its natural moisture content is higher than its liquid limit. Its lateral swelling pressure is around 2–10 times larger than the vertical swelling pressure [1]. The unconfined compressive strength is between 25 to 50 kPa [2]. These properties showed that marine clay is not suitable for use as a foundation material. Therefore, Geotechnical Engineers must provide solutions to this problem through soil stabilisation.

Stabilization of marine clay has received considerable attention in the relevant literature. Material like cement[3]–[8] and lime [9]–[12] were reported to have successfully stabilised marine clay. Although the improvement of strength is good enough, however, the price of these materials and the extended curing period they require makes it prohibitive. Other researchers treated the marine clay with waste material. Materials like rice husk ash, carbide slag [13], sawdust [10], locust bean waste ash [14]–[17], banana fibre [18], crumble rubber [19], ceramic waste [20], and ground granulated blast furnace slag [21]. However, these waste materials were only able to reduce the cost but unable to minimise the curing period.

Therefore, another option is the applications of chemicals. Inorganic materials like Sodium silicate [13], [22]–[24]; and an organic chemical like N-Methylolacrylamide, Epoxy resin, Amino plast, Phenoplast, Lignosulfonate [25], [26]. However, the rheological properties, environmental impact, toxicity and local regulations limited the use of chemicals for soil stabilisation. Nevertheless, the promising properties of Polyurethane like high strength, low viscosity and density, short gelling time and inertness chemically after hardening are encouraging and lead to this research on investigation its application to stabilise marine clay.

Previous findings showed that polyurethane has been in use for civil engineering projects in many countries like USA, China, Italy, Korea, Malaysia, Iran and many more. Application of polyurethane grout in soil nailing decrease settlement of the ground from 5.33mm to 2.002mm and from 4.71mm to 1.818mm respectively [27]. Similarly, application of the polyurethane grout as micro piles modify the dynamic response of the ground [28], [29]. Injecting Polyurethane foam into the pavement subgrade improved the strength, stiffness and bearing resistance of the pavement [30]–[32]. Furthermore, [28] and [33] recommended Polyurethane grout for remedial action during Tunneling. However, there is no report of application polyurethane to stabilise marine clay. Therefore, this paper intend to report the laboratory investigation of the application of Polyurethane chemical for stabilisation of marine clay.

Polyurethane is a polymer material that is synthesis by the chemical reaction between the diisocyanate and a polyol to produce the urethane which is the repeating unit in Polyurethane[31], [34]–[36]. The properties of Polyurethane depend mainly on the type of Isocyanate, polyol and additives used in its synthesis process [37]. Polyurethane is now used globally as a construction material [35], [38], [39].

## 2. Materials and specimen preparation

The materials for this research are marine clay (soil) and rigid Polyurethane (stabiliser) shown in **Error! Reference source not found.** A disturbed sample of marine clay was obtained from Batu Pahat in the campus of Universiti Tun Hussein Onn Malaysia (UTHM) Johor Bahru Malaysia. Backhoe excavator excavated the sample at a depth of 1.5 m. NCL Chemical & Equipment, Selangor Malaysia supplied the rigid Polyurethane. Table 1 shows the properties of the Polyurethane given by the manufacturer.

The collected marine clay sample was air dried for two weeks and then ground to smaller particles sizes as per [40] standard procedure for dry sample preparation. Then, the dried soil samples undergo a series of laboratory tests as per [41]–[43] standard procedure for the characterisation of the soils. The tests carried out for the characterisation of the marine clay are Atterberg limits tests, grain sizes analysis, moisture-density relationship, PH test, Lost of Ignition test and unconfined compressive strength (UCS) tests.

Performing unconfined compressive strength tests (UCS) on marine clay evaluated the effect of Polyurethane on marine clay properties. The marine clay mixed with optimum moisture content (OMC) and different dosage of polyurethane. The volume of Polyurethane that corresponding to 0%, 1%, 2%, 3% 4% and 5% of the bulk mass of the soil sample was added and mixed with the soil and compacted as quick as possible before the hardening of the Polyurethane and soil. The moulded and compacted soil was allowed to stay in the mould for some few minutes for the reaction of Polyurethane to complete before extruding from the mould and then tested with the UCS testing machine after 1-day curing. The 0% Polyurethane content samples were tested immediately after compaction. The tests were repeated twice in order to ensure the consistency of the results.

**Table 1.** Properties of polyurethane specified by the manufacturer

Properties	Unit	Components of the Polyurethane	
		Polyol	Isocyanate
Appearance	-	Amber liquid	Dark brown liquid
Viscosity at 25 <sup>0</sup> c	mPa.s	260 ± 50	185 ± 35
Specific gravity at 25 <sup>0</sup> c	-	1.15 ± 0.01	1.24 ± 0.01
Recommended mixing ratio	g	125	140
Cream time	sec		40.0 ± 3.0
Gel time	sec		250.0 ± 10.0

Free rise density	$\text{Kg/m}^3$	$45.0 \pm 3.0$
Demold time	min	>30



**Fig. 1.** Polyurethane consisting of Polyol and Isocyanate

### 3. Results and discussions

#### 3.1. Basic Material Properties

The untreated marine clay was characterised based on the result of tests conducted in the laboratory. Table 2 shows the results of a characteristic of the marine clay. From this result, the marine clay under review has natural moisture content of 67%, liquid limit and plastic limit of 65% and 26 % respectively. These values are similar to the properties of marine clay reported by [1], [9], [44] and slightly lower than that reported by [18]. The result of the particles sizes distribution further confirmed that the soil has a fine fraction (particles smaller than 63um) up to 98%, optimum moisture content (OMC) of 25% maximum dry density MDD of  $1440\text{Kg/m}^3$  and loss of ignition (LOI) of 8%. All these values fall within the ranges of most common marine clay soils reported by many scholars as reviewed by [2]. However, the PH value of 3.25 for this marine clay has the acidic property that is unusual as reported by [45].

**Table 2.** Properties of marine clay

Properties	Results
Natural moisture content	67%
Liquid limit	65%
Plastic limit	26%
Gravel fraction	0%
Sand fraction	1.32%
Fines fraction	98.68%
OMC	25%
MDD	$1440\text{kg/m}^3$

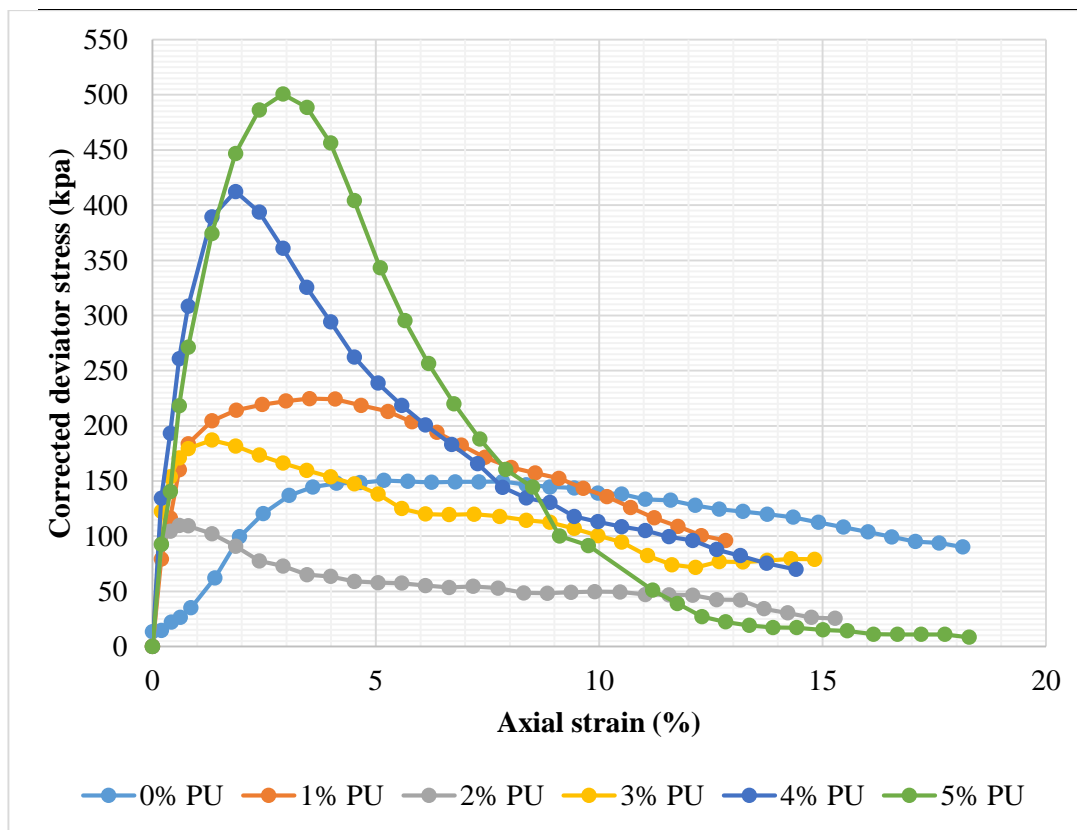
PH	3.25
LOI	8%

**3.2. Effect of Polyurethane on the properties of marine clay**

Table 3 **Error! Reference source not found.** and Fig. 2. UCS test result of marine clay at varying dose of Polyurethane. The result shows the effect of Polyurethane on the shear strength parameters of marine clay. The result revealed that 5% of Polyurethane improved the shear strength of the marine clay from 75 kpa to 250 kpa (more than 230%) improvement. This improvement of the shear strength of marine also caused the corresponding decrease in the cumulative strain of the marine clay from 5.18% to 2.92% (that correspond to more than 77% decrease) in the cumulative strain of the marine clay. This result shows that the marine clay which is not suitable in its natural condition for use as subgrade material or as foundation materials can be improved by application polyurethane as a stabiliser.

**Table 3.** Result of the effect of Polyurethane on marine clay

All Stages Conditions at Failure			
Polyurethane content (%)	Maximum Corrected Deviator Stress (kPa)	Cumulative Strain (%)	Shear Strength (kPa)
0	150	5.18	75
1	224	4.09	112
2	110	0.60	55
3	187	1.33	94
4	412	1.86	206
5	501	2.92	250



**Fig. 2.** UCS test result of marine clay at varying dose of Polyurethane

From the result of Table 3. Result of the effect of Polyurethane on marine clay, initially at 0% Polyurethane (untreated soil), the deviator stress was 150kpa. Adding 1% Polyurethane into the soil causes the deviator stress to increase slightly, and a further increase in Polyurethane by 2% caused the deviator stress to drop below the initial value of deviator stress of untreated soil. However, subsequent increases of Polyurethane (3%, 4% and 5%) caused continues to increase in deviator stress of the marine clay. The fluctuation in improvement between 1%, 2% and 3% Polyurethane content is probably from the sample preparation. Likely the 2% and 3% specimen were extruded before the Polyurethane finish reaction and hardened in the mould. Moreover, that caused the specimen to be cracked, and it cannot attain the exact strength.

Furthermore, attempt to increase the Polyurethane content above 5 % proved abortive, as the mould can no longer accommodate the volume of the soil mixed with the Polyurethane. At the polyurethane content more than 5%, once the reaction of Polyurethane commences, the mixture of Polyurethane foam and soil will force its way out of the mould due to the numerous increase in the volume of Polyurethane during the reaction [46]. The Polyurethane increases in volume up to 20 times of its original volume [47]. That increase in volume can cause uplifting of a depressed section of concrete pavement to the desired level [31]. The expansion of the Polyurethane also results in demanding only a small quantity of Polyurethane, that results in the cost saving.

## 4. Conclusion and recommendations

From the information gathered and the experimental studies conducted, the following conclusions and recommendations are made on the application of Polyurethane for stabilisation of marine clay.

### 4.1. Conclusion

The results of the preliminary results showed that the soil has all the attributes of marine clay such as a liquid limit of 65%, plastic limit of 26% and plasticity index of 53%, percentages of gravel, sand and fines in the sample respectively equal to 0 %, 1.32 % and 98.68 %. Compaction characteristics of the soil (OMC and MDD equal to 25% and 1440kg/m<sup>3</sup>) respectively. A soil PH of 3.25 and LOI equal to 8%. All these confirmed that the soil is marine clay and is not suitable for construction purposes at its natural condition.

Stabilizing the marine with the polyurethane improved the shear strength of the marine clay from 75 kpa to 250 kpa it further reduces the cumulative strain of the soil from 5.18% to 2.92% which correspond to improvement by 230% increase in shear strength and 77% decrease in cumulative strain.

Utilization of Polyurethanes a stabilisation material for marine clay is technically viable mainly due to its short gelling and hardening time will make it an excellent and quick improvement method, speedy construction and handy for remedial works. The multiples increase in the volume of Polyurethane also confirmed during sample preparation Polyurethane and marine; and it will be the useful maintenance of depressed pavement, road hydraulic structures, buildings and other underground construction where standard or conventional method will be infeasible.

### 4.2. Recommendations

A further study is recommended on the sample preparation to determine the time limit of completing the mixing and compacting the marine clay and Polyurethane foam into the mould, and the minimum time the sample must stay in the mould before it can be extruded out.

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