Geotechnical characteristics of the Barton Clay

Allamin Muhammad, Aminu Abdullahi Isyaku & Adedayo Agboola

Abstract— The geotechnical properties of the Barton Clay from the Hampshire Basin in England are presented. Barton Beds are important lithologies for many prominent micro and macro fossils in Britain. The common index properties of the clay soil for engineering including moisture content, plasticity, liquid limit and shrinkage limits are investigated. Mineralogical properties of the clay to determine its expansive potential are determined using X-Ray Diffraction. Scanning Electron Microscopy (SEM) and Energy Dispersive X-Ray (EDX) were used to determine the clay fabric properties. The characteristics of the Barton Clay from samples obtained at the type locality for the soil at the Barton-on-Sea area as well as from exposures in the Isle of Wight are compared.

Index Terms— Barton Clay, Barton-on-Sea, Geotechnical, Geology, Index Properties, Sampling

1 INTRODUCTION

This paper describes the geology and geotechnical properties of the Barton Clay Formation from the Barton-on-Sea and the Isle of Wight in the Hampshire Basin of southern England. The study was achieved through field work and laboratory studies. Index properties of the Barton Clay including plasticity, moisture content, liquid limit, shrinkage properties, mineralogy and fabric structure studies from representative samples were carried out. Barton Clay Formation consists of layers of grey, greenish and brown clays intercalated with sands forming good cliff exposures at Barton-on-Sea and the Isle of Wight. The British Geological Society Lexicon described the formation as Olive grey and greenish grey shelly clays of varying sand content with fine-grained clayey, commonly glauconitic, sands and flint pebble beds forming in the lower part of the sequence. Barton-on-Sea is the type locality for the formation and provides good sources of well preserved macro and micro fossils. Exposures of the Barton Clay Formation are localised in the Barton and Highcliffe in Christchurch Bay, at Alum Bay and at Whitecliff Bay in the Isle of Wight of the Hampshire Basin of southern England, United Kingdom.

2 STUDY AREAS

Main study area is the Barton-on-Sea is located on the English south coast about 10 km east of Bournemouth, United Kingdom lying between Highcliffe and Milford-on-Sea along Christchurch Bay. The area comprises of 1.75 km of coastal cliffs and slopes forming southern part of the English coastline (Fig. 1). These cliffs range in height from 30 to 35 meters and composed of soft often very fine grained Eocene sequences capped unconformably by Pleistocene gravels and brickearths (Melville and Freshney, 1982). The Whitecliff Bay in Isle of Wight located in the English Channel southern England is the secondary study area.

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3 GEOMORPHOLOGICAL SETTING

The topography of the site at Barton-on-Sea is characterised by a series of terraced slopes and sedimentary cliffs rising upwards from a narrow beach to a plateau at approximately 31 moD. The cliff at the upper part consists of a naturally occurring near vertical cliff face with variable height with a colluvial slope having a characteristic inclination angle 30^0 to 34^0 at its toe. The undercliff often consists of a series of scarps lying below the talus. This is separated by benches with widths ranging between 5 to 10 m which is now used for accessibility in the area. The cliffs are characterised by the presence of series of sands and clays dipping gently to the east enabling the development of a series of stratigraphically controlled bedding plane shear surfaces at various stratigraphic horizons (Barton, 1973). Vast majority of the slopes along the frontage of this area have been historically subjected to marine toe erosion and as a result numerous phases of investigation, coast protection and landslide stabilization measures have been carried out at the site. Although clear reasons as to why these weak horizons develop might not have really been established, many of these failures (occurring along these slip planes) could partly be attributed to high pore pressure and inadequate drainage measures. Pore water pressure develops due to the fact that water infiltrating through the Plateau Gravel and Upper Barton Beds from precipitation and other sources is inhibited from draining downwards into the underlying low permeability Middle Barton Beds. The cliff landslides operating here are mainly of the compound type (Skempton and Hutchinson, 1969), showing a basal translational shear surface coinciding with a bedding plane (Barton et al., 2006).

4 GEOLOGICAL SETTING

The Barton Clay is of the Bartonian age of the Upper Eocene analogous in age with the famous Eocene gypsum in Paris Basin whence the term Plaster of Paris (PoP) is referred (Harland et al., 1982). White (1921), Curry et al. (1972) and Murray and Wright (1974) identified the three fold divisions of the Barton Beds of Alum Bay in Isle of Wight. The Lower Barton comprises 17 m of grey or brown clay with scattered septaria and many small fossils. The base is marked by *N. Prestwichianus* while the upper part marked by N. Rectus (Daley, 1998). The Middle Barton has a thickness of 51 m in Alum Bay and consists of grey, green and brown clays being sandy in places and contains some layers of concretions. Abundant

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fossils including *Athleta luctator*, *Crassatella sulcata, Sycostoma pyrus and Corbula pisum* were observed (Curry et al., 1972). In addition to these fossils, corals, wood fragments and shark teeth are also reported to have been observed (White, 1921). The diverse marine fauna in this sequence seems to indicate normal marine salinities. The possibility of sediment-starved offshore shelf condition is suggested by the marked concentration of glauconite at a number of horizons (Plint, 1982).

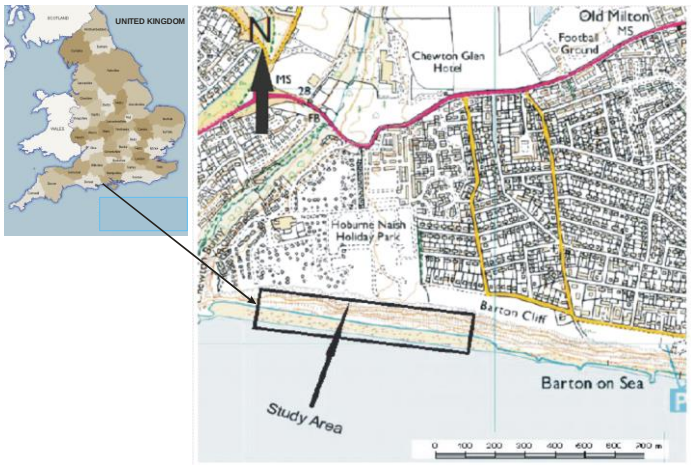

Fig 1. Main Study area location at the Barton-on-Sea, southern England

Lithologically the Barton Clay is divided into four categories, comprising of Lower Barton Bed or Highcliffe Member, Middle Barton Bed or Naish Member, Upper Barton Bed or Becton Member as well as Lower Headon Bed or Huddle Member identified at Alum Bay Isle of Wight (Melville and Freshney, 1982). The type section of the Formation is found in the Highcliffe Barton-on-Sea and runs from Cliff End, about 1 km east of Mudford, to Paddy's Gap near Milford. The thickness at Highcliffe is 67.5 m with increasing thickness in the south-east direction to about 102 m at Alum Bay and 111 m at Whitecliff Bay in Isle of Wight. Burton (1933) established 14 divisions which are only recognised in the type section. Fig. (2) shows the general lithological characteristics and most prominent fossils of Barton Formation. The base of the formation is marked by a bed of flint pebble at Cliff End which separates underlying sands from 3 m of overlying clay. This bed is in turn followed by glauconitic sandy clay, i.e. Bed A1 of Burton characterised by *Nummulites prestwichianus* indicating a more open sea with conditions being more turbulent. *Nummulites rectus* is found in Bed A2 located 6 m above *N. Prestwichianus* and is the last known Nummulites in Britain. Beds C, E and H are the most fossiliferous having yielded some 600 species of molluscs. Some hundreds of species including *Cornulina minax, Clavilithes macrospira, Cardidcardia sulcata* and *Crassatella sulcata* were found in Bed E alone. The boundary between Bartons Beds F and G composed of fossils which indicate that the sea level was shallow at the beginning of Barton times, continued to deepen until the episode of Bed H known as the Chama Bed. Bed I contains no fossils while Bed K shows the first symptoms of progressive change from brackish to freshwater conditions in the overlying Hordle Member. A massive cream-coloured limestone, known as the How Ledge Limestone marks the top of the Hordle Member at Headon Hill and Colwell Bay in the Isle of Wight (Melville and Freshney, 1982).

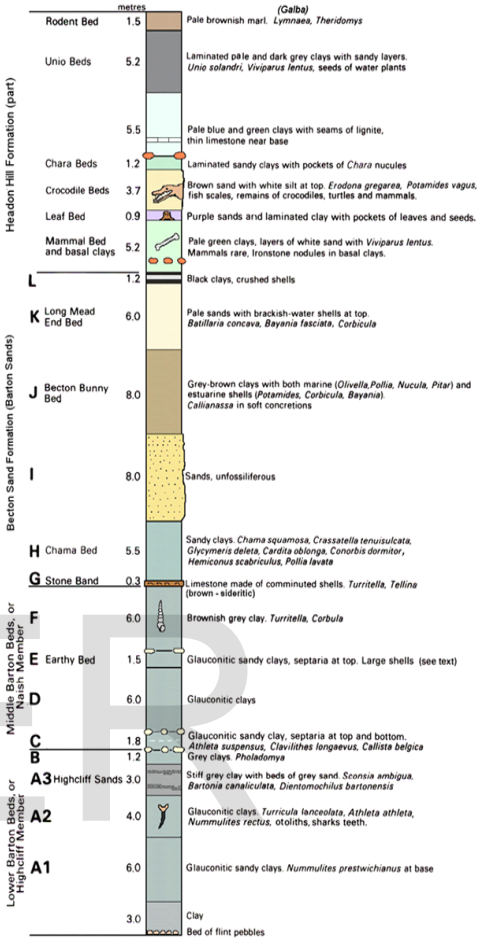

Fig 2. Lithological characteristics and most prominent fossils of Barton Formation

In the Isle of Wight the Barton Formation is represented by clays overlying the Brackelsham Beds in both Alum Bay (Fig. 3). These deposits, composed of sandy clays, clays and sands with layers of Septaria, have a nature that is well displayed in the sections of Alum Bay where they attain a thickness of 250 feet (Bristow, 1889). Barton Beds were divided by Gardner *et al.* (1888) into three classes; the Lower, Middle and Upper Barton. Edwards and Freshney (1987) regarded the first two of these as Barton Clay while the last is assigned to the Chama Sand and the succeeding Becton Sand.

In Whitecliff Bay most of the section of Barton Clay is hidden by vegetation and slips and are poorly exposed. The muds are characterised by blue grey colour with sections that further deteriorated as a result of its use as an access way to beach and some cliff protection works (Daley, 1998). The formation is best studied foreshore and in low tides when the modern beach sediment is removed by storms. A rich and well preserved calcareous nannofossil assemblage are reported to have

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been found by Aubry (1986) in the Lower Barton Beds but the Middle and Upper Barton beds were barren of calcareous nannofossils. At the base of the formation, about 8 m above the erosion surface macroinvertebrate remains from the foreshore including corals were seen (Hugget and Gale, 1997). Molluscs also occur in numerous horizons but are sometimes present as reworked debris near the top of the sequence. A restricted foraminiferal assemblage associated by *N. Prestwichianus* was found by Murray and Wright (1974) and as a result reached the conclusion that the abundance of Rotaliina genus *Cibicides* among the foraminiferal assemblage indicated the presence of hypo-saline water and muddy shelf conditions with depths up to 100 m. An overall regressive trend can be inferred as the Barton Clay passes through Chama Sand to Becton Sand and subsequently the Solent Group.

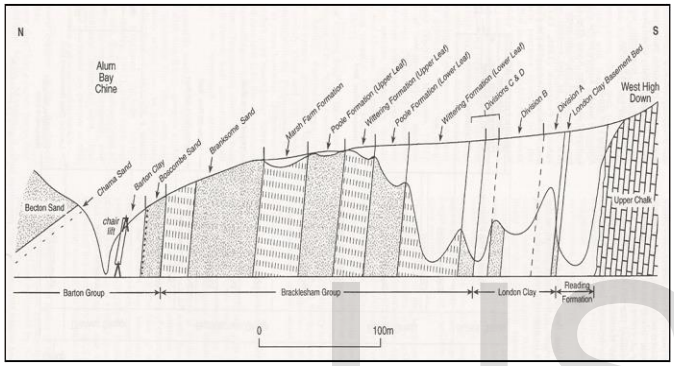

Fig. 3 Cliff section at the Alum Bay Isle of Wight

At the Barton-on-Sea area the whole outcrop is overlain unconformably by Pleistocene deposits (Fig 4). It is a continuous unfaulted sequence extending over a length of 4.8 km. The beds are characterised by an average dip from west to east of approximately 1-2^{o} but the true dip being approximately 3-4^{0} ENE, making it shallow enough to be regarded practically horizontal when viewed across the shore. The cliffs attain a height from about 15 m at the western end to nearly 30 m over the rest of the outcrop. However the point on the cliff where cut through by the stream known as Chewton Bunny is an exception as the height of the cliff here is far less than 30 m.

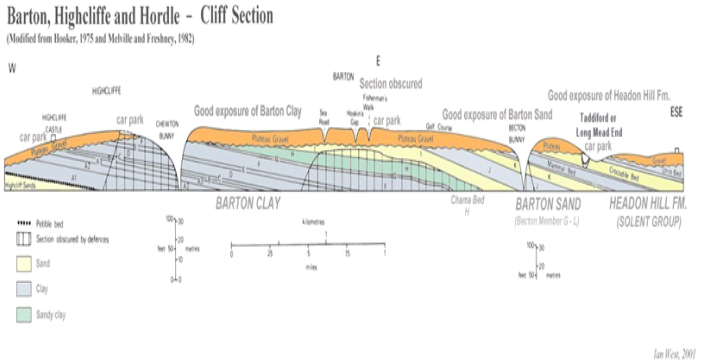

Fig 4. Cliff Section showing different zones of Barton Clay present at Barton-on-Sea

The area between the cliff top and the landward end of the beach (defined as the width) varies from less than 30 m in the west to about 91.5 m over the main area and subsequently reduces to about 70 m in the east. Stiff overconsolidated Barton Clay known as the Middle Barton Beds form the majority of the undercliff while towards the upper part of the slope and inland cliff are formed from Barton Sands composed of silty fine sands over a sandy clayey silt sequence called the Chama Bed (Barton, 1973).

HYDROGEOLOGY

On the basis of piezometric data and field observation of seepages, a hydrogeological model has been constructed by Rendel Geotechnics (1998) based on five main hydrological units. These include Plateau Gravel, Upper Barton Beds, Middle Barton Beds, Highcliffe Sands, colluviums, landslide debris and fill. The Plateau Gravel and Upper Barton Beds units together form a partly confined aquifer infiltrating water from rainfall and other sources is inhibited from percolating downwards owing to the presence of the underlying low permeability clay of the Middle Barton Beds. The flow is at some point partly restrained by the presence of low permeability colluviums/talus, leading to the development of pore water pressure and, to a local extent high water tables. Highcliffe Sands in the Middle Barton Beds shows characteristics of a confined aquifer of different hydraulic properties to be differentiated from the surrounding deposits and as such may be regarded as a distinct hydrogeological unit. Groundwater investigations show that piezometric heads in Highcliffe Sands are typically some few meters above sea level, often indicating flow in a direction towards the sea. These heads are also found to be much lower than hydrostatic below the water table existing in the Plateau Gravel/Upper Barton Beds, or the landslide debris thereby indicating the presence of perched water table and insufficient drainage of the underlying Barton Clay directly into Highcliffe Sands (Fort et al., 2000).

CLAYS PROPERTIES

ELASTICITY OF CLAYS

Elastic materials such as clays are described as being either isotropic or anisotropic. An isotropic elastic material is one in which the elastic properties are not dependent on the coordinate axis to which the properties are referred. Thus when a sample is cut from such a material it exhibits the same elastic properties regardless of the orientation of the sample. Sample orientation refers to its orientation with regard to the parent material and it excludes the trivial rotations which may occur after the sample is removed from its original position. Elastic constants including the Young's modulus *E*, Poison's ratio v, Bulk modulus *K* and shear modulus *G* may aid in describing the elastic behaviour of the material. Conversely a material in which the elastic properties are solely dependent on the orientation of the sample is referred to as anisotropic. The elastic properties of a soil are sometimes assumed to be dependent on the mode of deposition and stress history of the soil. A soil

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deposited vertically and then subsequently subjected to equal horizontal stresses will therefore be expected to exhibit a vertical symmetrical axis and be transversely isotropic. Tectonic and geomorphological processes such as crustal movements, tilting, erosion, moving ice sheets and solifluction may produce soils with varying stresses in different directions. Clays are generally known to be characterised by non-linear elastic properties based on extensive tests on remoulded materials designed for determining strength parameters, and consolidation tests in which the preconsolidation pressure is exceeded. Central characteristic of some more complex models for soil behaviour is shown by an initial range of elastic behaviour. For small changes in stress, non-linearity in the volumetric behaviour is insignificant and the predicted behaviour generally approximates to that of linear isotropic elasticity (Graham and Holsby, 1983).

SWELLING AND SHRINKAGE BEHAVIOUR OF CLAYS

Expansive soils swell and shrink regularly when subjected to annual moisture changes. These soils are available throughout the world and continue causing substantial problems to buildings. An estimated annual cost of damage due to expansion of soils is $1,000 million in USA, £I50 million in the UK and many billions of pounds worldwide (Gourley et al., 1993). The primary reason expansive clays cause significance damage is attributed to their shrink-swell behaviour. In arid and semi-arid areas where there is large seasonal variation in moisture and rainfall, small structures and highways constructed on expansive soils are exposed to periodic cycle of swelling and shrinkage. The outcome of this inevitable phenomenon is the undesirable cracking and fatigue to structures. Popesco (1980); Osipov et al. (1987); Day (1994) inferred that swelling potential of clays increases with the number of wetting and drying cycles when samples are allowed to completely shrink to a moisture content equal to or less than the shrinkage limit.

Table 1: Soil expansivity prediction by liquid limit (after Sridharan and Prakash,2000)

Degree of Expansion	I_P, %		
	Holtz and Gibbs (1956)	Chen(1975)	IS 1498 (1970)
Low	<20	0-15	<12
Meduim	12-34	10-35	13-23
High	23-45	20-55	23-32
Very High	>32	>35	>32

However almost all previously indicated studies noted that the expansion reaches an equilibrium condition after about 3 to 5 cycles. Some of the many criteria available for the identification and characterisation of expansive soils are liquid limit (Table 1), plasticity index (Table 2), shrinkage limit, shrinkage index, free swell index (FSI) and percent free swell (Table 3).

Table 2: Soil expansivity predicted by liquid plasticity index (after Sridharan and Prakash, 2000)

Degree of expansion	WL: %	
	Chen (1975)	IS 1498 (1970)
Low	<30	20-35
Medium	30-40	35-50
High	40-60	50-70
Very high	>60	70-90

Table 3: Soil expansivity prediction by other measures (after Sridharan and Prakash, 2000)

Degree of expansion	(%)Colloidal content (Holtz and Gibbs, 1956)	(%) Shrinkage limit (Holtz and Gibbs, 1956)	(%) Shrinkage index (IS 1498, 1970)	(%) Free swell index (IS 1498, 1970)	(%) expansi-si-onHoltz andGibbs (1956)	(%) expansion Seed et al. (1962)
Low	<17	>13	<15	<50	<10	0-15
Medium	12-27	8-18	15-30	50-100	10-20	1.5-5.0
High	18-37	6-12	30-60	100-200	20-30	5-25
V. High	>27	<10	>60	>200	>30	>25

METHODOLOGY

The methodology for the geotechnical characterisation of the Barton Clay here involved both field and laboratory investigation. The study focuses mainly on the Barton Clay of the Barton-on-Sea due to its good cliff exposure, however, Barton Clay of the Isle of Wight was also obtained for comparison. The field aspect involves the sampling regime while the laboratory investigations involve testing of common index properties, mineralogical and micro fabric investigations.

Sampling

Site visits were carried out in order to collect the Barton Clay samples exposed at two different locations for laboratory investigation according to recommended practice given in the BS 1377 (1990). The first sampling location is at the Whitecliff Bay situated in the east coast of the Isle of Wight where the formation is poorly exposed as a result of slips. The samples were collected by digging nearly half a meter depth in order to retrieve a fairly in-situ representative sample. This was initially done by digging a small pit using a spade and subsequently cutting block samples having a rectangular shape. The clay seemed hard and brittle thereby making it difficult to cut to a greater thickness. The sample was thoroughly wrapped in a cling film in order to suppress loss of moisture. It is then labelled appropriately in a polythene bag. The second and the main sampling location is at the Barton-on-Sea, where most

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samples for this study were obtained, is located on the English southern coastline between Highcliffe and Milford-on-Sea of the Christchurch Bay area. The samples here are better exposed than at the Isle of Wight.
The samples collected were labelled Sample A, B, C and D. Sample A was collected from the Whitecliff Bay, Isle of Wight coastal exposures. Sample B was collected from the C Zone of the Barton Clay coastal cliffs at the Barton-on-Sea cliff exposures. Sample C was collected from the middle portion (along the D Horizon) at the Barton-on-Sea cliff exposures. Sample D was collected from the upper part (along F1 Bed) of the cliff at the Barton-on-Sea cliff exposures. This sampling strategy is to ensure a fairly representative collection of the Barton Clay at various locations for analysis. The samples collected were tested in the Soil Mechanics Laboratory of the University of Portsmouth, United Kingdom to ascertain their moisture content, liquid limits and plasticity. Mineralogical properties were investigated using x-ray diffraction and micro fabric structure was determined using scanning electron microscopy.

LABORATORY INVESTIGATIONS

Index Properties of the Barton Clay

Moisture content, liquid limits, plastic limits, consistency limits and shrinkage limits are the index properties of the Barton Clay that were investigated. Other tests carried out include; shear strength, linear shrinkage, x-ray diffraction and mineralogy all according to BS 1377 (1990).
The liquid limit, the plastic limit and the plasticity index are related to the mineralogy and the amount of clay present in the soil specimen. The water content at which it undergoes changes in its consistency is the consistency limit also known as the Atterberg Limit. Most natural soils contain water as part of its structure. The amount of water, expressed as a proportion by mass of the dry solid particles known as the moisture content usually has a great influence on the soil behaviour. Moisture content is used as guide to classify natural soils and also as a control criterion in recompacted soils for most field and laboratory tests. In this laboratory analysis, the oven drying method was used. The oven drying method covers the determination of the moisture content of a specimen of soil as a percentage of its dry mass. Cone penetrometer method was used to determine the liquid limit of the clay samples. It is preferable to the earlier Casagrande method owing to its simplicity and ease, and is based on the measurement of penetration into the soil of a standardised cone of a specific mass.

Moisture Content Test

The moisture content of a specimen of the soil is determined as a percentage of its dry mass. A clean and dry metal container was weighed to the nearest 0.01 g. A sample of about 30 g was taken, crumbled and then placed in a loose manner in the container and the lid was placed. The container and its contents were then weighed to the nearest 0.01 g. The lid was removed from the container and both were placed in the oven and dried at 105^0C. After drying, the container with its content was removed from the oven and then placed in the desiccator to cool. The lid was then replaced and the container were weighed together with its contents to the nearest 0.01 g. Individual readings were recorded.

Liquid Limit Test

The clay material was mixed for 10 minutes on a glass plate. The material was then placed in a stainless steel cups. The Cone Penetrometer instrument was supported with its apex just touching the surface of the soil sample in the stainless steel container. The cone was then allowed to fall into the tin (container) and the penetration was recorded to the nearest 0.1 mm after a period of 5 seconds. After getting the mean penetration value, the sample was transferred to an oven maintaining a temperature of 105^o C. The cone was then carefully cleaned and the test was repeated about 3 times on the same sample at higher water content to obtain greater penetrations. The moisture content of the sample tested at different water content was recorded a day after.

Plastic Limit Test

About 20 g of the mixed clay sample was taken and spread on glass mixing plate so that it could partially dry. When the soil paste was plastic enough, it was well kneaded and shaped into balls. The ball shaped soils were mould between fingers and rolled between the palms so the warmth of the hands slowly dried it. When slight cracks began to appear on the surface, the ball was divided into two portions each of about 10 g. Each portion was further divided into four more or less equal parts and the set of each four equal parts kept together.
Each of the parts was kneaded by fingers so as to ensure regular distribution of moisture and later formed into a thread about 6 mm diameter and rolled further into 3 mm diameter.
When crumbling stage was reached, the crumbled threads were gathered and placed into a pre-weighed moisture content container and lid was placed immediately and transferred to the oven for drying.

SAMPLE	% MOISTURE CONTENT (w)	% PLASTIC LIMIT (PL)	% LIQUID LIMIT	% PLASTICITY INDEX (Ip)
A	17.1	17.7	40.5	22.8
B	30.68	15.03	52.5	37.47
C	20.63	22.84	50.1	27.26
D	22.68	22.53	50	27.47

Table 4. Summary of the results of the index properties of the Barton Clay samples

The summary of the results of the index properties of the Barton Clay samples tested in the laboratory is given in Table 4. The plasticity chart (Fig. 5) reveals that sample B which plotted above the A-Line is highly plastic clay. Sample C and D both exhibit almost similar characteristics (in terms of plasticity) as they are classified as clays of medium plasticity (also plotted above the A-Line) but appear to be very close to the interface between the medium plasticity and high plasticity.

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Sample A which plots above the A-Line is also a medium plastic clay.

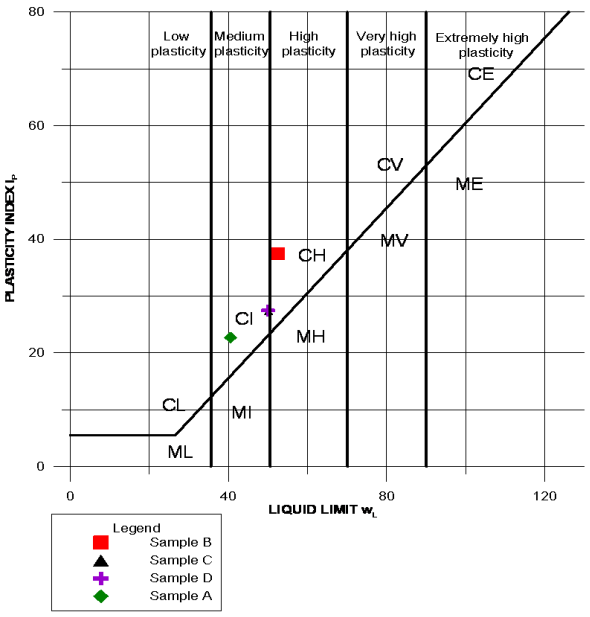

Fig. 5. Plasticity Chart showing plasticity index for the Barton Clay samples

Linear Shrinkage Test

Linear shrinkage test was carried out to determine the percentage linear shrinkage of the clay soil. About 150 g of the Barton Clay sample in its natural state was placed on a glass plate and thoroughly mixed with distilled water continuously until it becomes a smooth homogeneous paste at about its liquid limit. In order to ensure accuracy, cone penetrometer was used to obtain a penetration of 20 mm. A thin film of petroleum jelly was added to the inner surfaces of a clean and dry mould so as to prevent the soil from sticking to the mould. The soil paste prepared was placed carefully in the mould avoiding air to be trapped so that the mould was slightly overfilled. The mould was then tapped gently to remove any air pockets. The top edge was then levelled with the aid of a pallet knife. Soil adhering to the rim of the mould was wiped off. The mould was transferred to the oven immediately after being left exposed to air so that the soil could dry slowly. The oven was initially set at 65^0C and after shrinkage has virtually ceased, the drying temperature was increased to 105^0 C to complete the drying process. The mould and the soil were allowed to cool and the length of the soil bar was measured using engineers steel rule to obtain the final length of the specimen.

Results obtained indicate that Samples B, C and D were curved after oven drying while Sample A was intact and showed no sign of curvature. This is probably due to the higher plasticity of samples B, C and D when compared to A. The summary of the linear shrinkage test result is shown in Table (5).

Table 5. Summary of linkage test for the Barton Clay samples

SAMPLE	ORIGINAL LENGTH (CM)	FINAL LENGTH (CM)	LINEAR SHRINKAGE (%)
A	140	130	7.14
B	140	123	12.14
C	140	122	12.8
D	140	120	14.2

Clay Mineralogy Test

Mineralogical properties of the Barton Clay samples were carried out using X-Ray Diffraction test. X-Ray Diffraction is a technique used in determining the nature and proportion of clay minerals present in mudrocks. This method generally relies on the manner in which the atomic structure of the mineral compound diffracts X-rays of certain wavelength and determines the arrangement of the atoms within the constituent crystals. In situation where interstratification exists within individual crystals, such as when illite and montmorillonite, or montmorillonite and kaolinite alternate at random within a single crystal, XRD yields misleading results and therefore care must be taken in the interpretation of clay minerals in such scenarios.

The sample was dried and disaggregated by gently grinding with an agate pestle and mortar. A small quantity of the powdered clay was placed into a small beaker containing distilled water. The beaker was then placed in an ultrasonic tank for at 15 minutes to aid further disaggregation. As the grinded particles may still be attached together, a deflocculating substance (NaPO3) was added. The clay suspension was transferred to a settling column (a measuring cylinder) and allowed to stand for 4 hours. The top 5 cm was pipette (2 µm suspension) and deposited on a glass slide, and allowed to dry. Three slides were prepared for each sample and placed in the X-Ray Diffraction Machine. Montmorillonite, illite and kaolinite groups are the most important clay minerals in geotechnical engineering. Montmorillonite undergo swelling upon contact with water, whereas clay minerals of the other two groups suffer considerably less. The magnitude of swelling depends largely on the quantity of montmorillonite minerals. Although the relative proportion of all the individual clay minerals present in Barton Clay cannot be known from qualitative XRD results only, it is obvious that the constituent clay minerals tested in the sample are mainly smectite, illite and kaolinite. However Bale (1984) has shown that smectite is relatively high in the Barton Clay at Barton (i.e. the type locality) with a remarkable abundance in the Middle Barton Beds. Smectite is usually high in the marine Eocene strata of Hampshire Basin. Whereas kaolinite, when compared to other parts of local marine Eocene strata, is fairly low. Figure (6) shows a model indicating the effect of various treatments on the *00l* reflection of oriented clay samples.

It can be depicted that in an air dried sample, smectite gives a characteristic *d* spacing and a peak respectively at 14 Angstrom and 6.40 2θ. When treated with ethylene glycol, smectite expands thereby showing a characteristic *d* spacing of about 17 Angstrom and a peak at an angle of reflection of 5.10 2θ.

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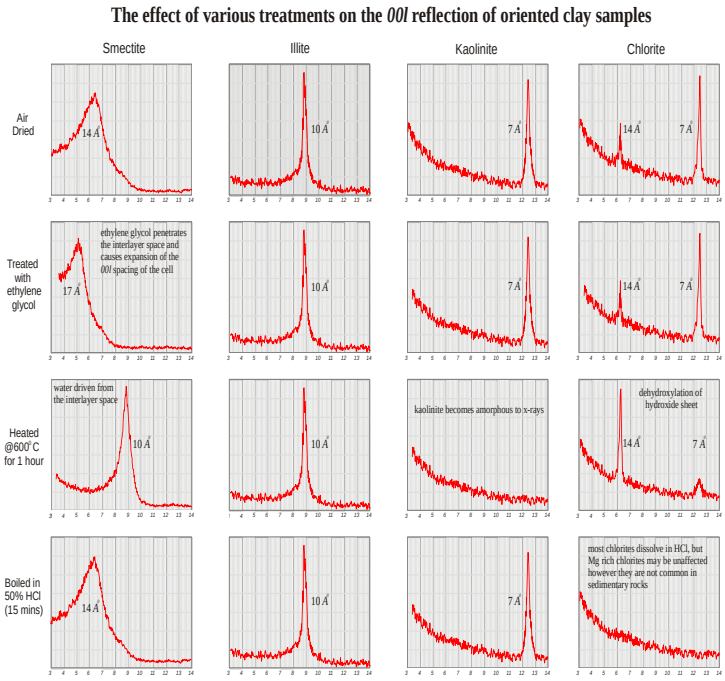
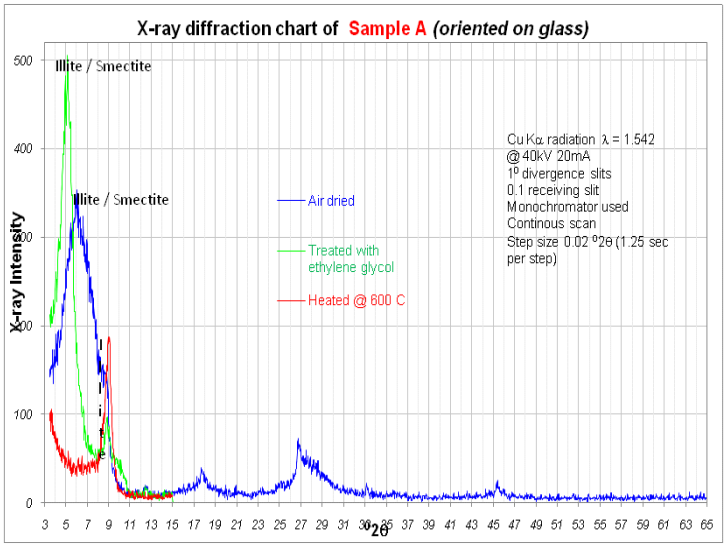


Fig 6. The effect of various treatments on the *00l* reflection of oriented Barton Clay samples

Smectite heated at 600^{0}C gives a peak at 8.90 2θ and a *d* spacing 0f 10 Angstrom. Illite, when air-dried usually possesses a *d* spacing of 10 Angstrom and a reflection angle of about 8.80 2θ. The same mineral when subjected to treatment with ethylene glycol and then heated at 600^{0}C shows no difference from the air-dried in both *d* spacing and reflection angle. Both air dried and ethylene glycol treated samples show kaolinite having the same properties (7 Angstrom *d* spacing and a peak at about 12.50 2θ) but becomes amorphous when subjected to a temperature of 600^0 C. Fig. 7. llite/Smectite interlayering in Sample A.



Depending on the relative proportion of either of the interlayered minerals, illite-smectite interlayering gives a peak at an angle less than or greater than the one given by smectite (non-interlayered). Sample B (Fig. 8), Sample C (Fig. 9) and Sample D (Fig. 10) all show similar composition as they are chiefly made up of smectite, illite and kaolinite. Subsequent peaks shown by air-dried samples at greater angles imply higher orders of reflection.

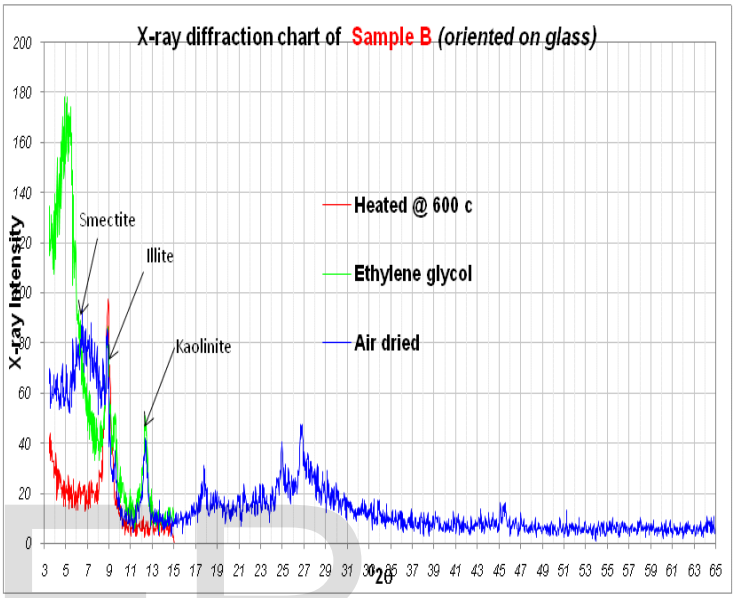


Fig 8. Smectite, Illite and Kaolinite signatures in Sample B

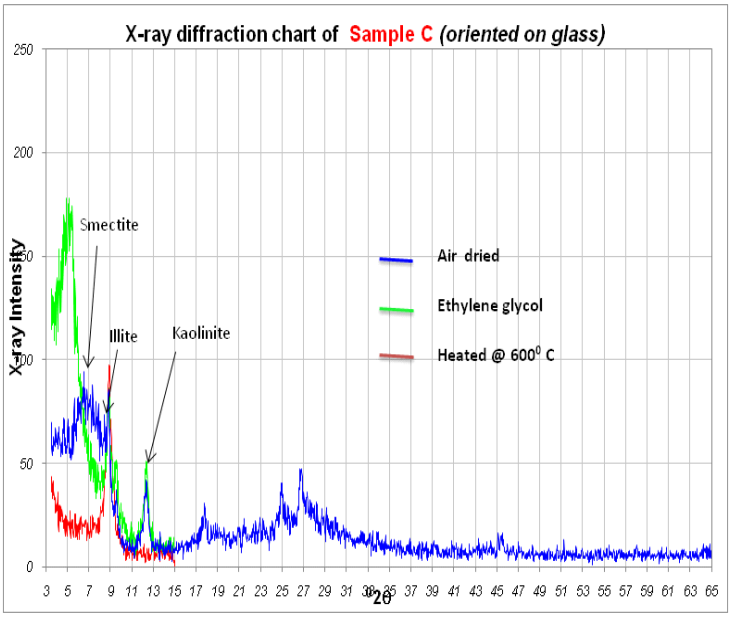


Fig 9. Smectite, illite and Kaolinite signatures in Sample C

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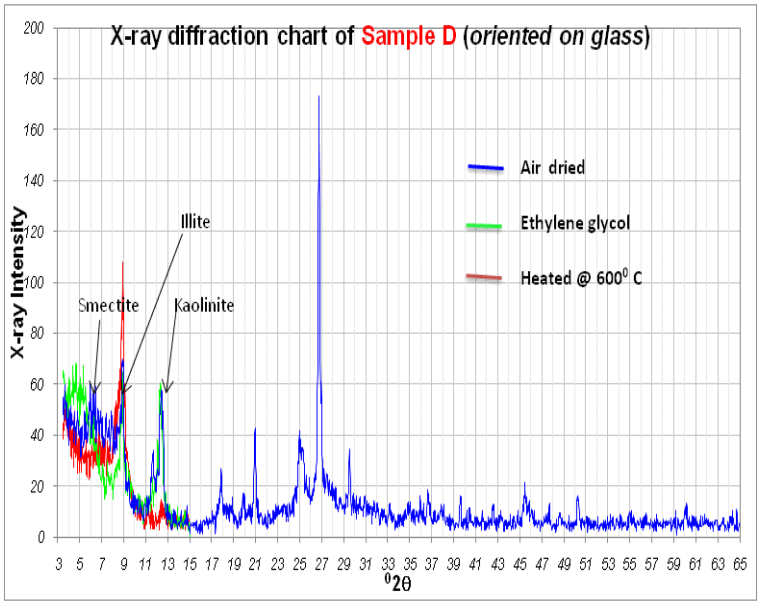

Fig 10. Smectite, Illite and Kaolinite signatures in Sample D

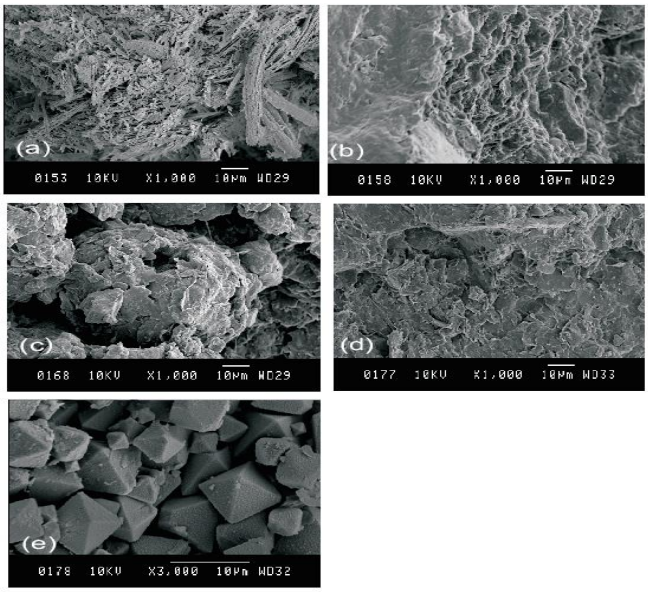

Fig. 11. Microfabric images of the Barton Clay Samples

Clay Microfabric Test

The microfabrics study of the Barton Clay was carried out using the Scanning Electron Microscope (SEM). The use of imaging techniques has enhanced microfabric studies of soils. A typical investigation of soil microfabric was carried out by Shi et al. (1999). Scanning Electron Microscopy is an effective and convenient tool for soil microfabric studies and as a result, applied by many soil scientists to extract and analyse the physical and mechanical properties of soils. Tovey, (1980); Smart and Leng, (1993); Shi et al., (1998); Martinez-Nistal et al., (1999) have used various techniques of image analysis to develop quantitative relationship between SEM images and characteristic features such as porosity, permeability, fractal dimension as well as aggregate orientation. Much information regarding particle morphology in soils can also be obtained with the aid of the image analysis. However interpretations that form the basis of soil properties described above are affected by soil magnification and as such scale is seldom quantitatively analysed in soil fabric studies.

The clay sample was coated with a thin conductive layer and the specimen is placed within the SEM sample chamber, and placed under a va cuum. A tungsten filament is charged with between 5 and 20 kilovolts (kV) of energy, which releases a beam of electrons onto the surfaces of the sample. The electron beam is focussed using electromagnets, and an image is produced on the main screen. The images were captured digitally onto a PC as a standard image file. Microfabrics of the four Barton Clay samples examined by the SEM are shown in Figure (21). This method shows that the samples are rich in clayey fabrics. Sample D (Fig. 11 (e)) shows the presence of a structure resembling pyrite framboids, as such an Energy Dispersive X-ray (EDX) investigation needs to be carried out to prove whether it was pyrite. Pyrite presence in soil can be a threat to stability by causing heaving.

Energy Dispersive X-Ray (EDX) Investigation

Energy dispersive X-ray (EDX) analysis works by applying a very high energy beam of electrons from the SEM to a selected area of a sample. This high energy beam excites the electrons in the different atoms of the sample, and as these electrons move to a higher energy orbit in the atom, others fill their space. The difference in energy (in kilo electron volts, or KeV) is measured by a spectrometer in the machine, and recorded. Each element in the periodic table has unique energy levels at which its electrons change orbit, so from this the elements present can be identified in the sample. If the sample has been coated in gold-palladium for SEM imaging, then these elements will also show up on the analysis. SEM examination of the samples reveals that Sample D (Figure 11 (e)) shows a crystal structure similar to pyrite. As a result, EDX technique was employed to clearly define such crystals. The image of the EDX spectrum, which shows peaks relating to the different elements that were detected in a spot analysis of the crystals which were thought to be pyrite is shown in Figure 12. The EDX supports the findings of the X-ray analyses, in that there doesn't appear to be a large amount of sulphur in the sample (as would be expected with pyrite, or iron sulphide). The main elements found were silicon and iron (with large peaks for gold and palladium - the metallic coating we added to the specimens) - a sulphur peak would be seen just to the right of the large gold (Au) peak if it were present. The crystal in question is presumably an iron mineral.

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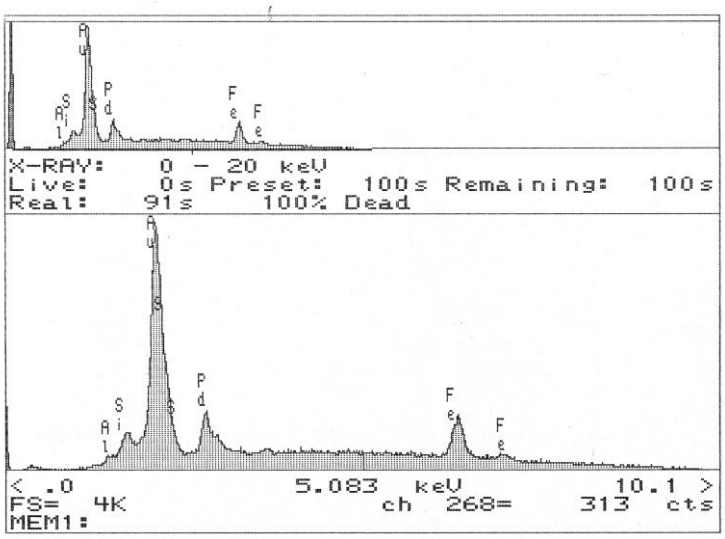

Fig. 12. EDX Analysis on Sample D

DISCUSSION AND CONCLUSION

Mineralogical analysis of the Barton Clay samples show that they are of illite, smectite and kaolinite. Illite is characterised by silicate layers that together with strong hydrogen bonds that cannot be broken easily except when the potassium cation is removed. Clay soils composed of illites are typical of soils deposited in temperate environments where leaching is less intense. Although there is no considerable difference the extent of its swelling when compared to illite, but kaolinite was found to swell to a greater extent. Both illite and kaolinite are bound by strong hydrogen bonds thereby preventing the soil from excessive degree of expansion. Kaolinite is often deposited in acid tropical soils in which leaching are usually intensive around rivers that drains in regions of tropical weathering (Tucker, 1991). This finding may be suggestive of the idea that Barton Clay was influence by more acidic fresh waters. Due to the constituent silicate sheets held by weaker oxygen bonds, montmorillonite is known to be the most expansive clay of all the groups. Mixed layer illite-smectite found in sample A may form as a result of leaching of illite/mica clay from the overlying strata. The presence of kaolinite in the samples indicates the non water absorption capacity of the clay due to the strong hydrogen bonding of the kaolinite layer structure. The presence of illites in the clay also indicates its non-expanding capacity owing to the non swelling ionic structure of illites. Although, the study did not clearly indicate the nature of the exact member of the smectite group present, the smectites in the clay would influence its engineering behavior due to its abiliy to expand and contract with addition and removal of water. Sample A obtained from the Isle of Wight did not indicate the presence of kaolinite while the other samples from the Barton-on-Sea indicate kaolinites presence.

The percentage liquid limits results from the Barton Clay samples indicated values ranging from 40.5 – 52.5 with the lowest value obtained from Sample A obtained at the Isle of Wight. This value range corresponds with 'High' degree of soil expansion for the Barton Clay based on Chen (1975) classification criteria for soil expansivity prediction. However this range corresponds to the Medium-High category based on the IS 1498 (1970) classification (Table 1).

Percentage plasticity index for the Barton Clay samples indicated values ranging from 22.8 – 37.47 with the lowest value also recorded in Sample A obtained at the Isle of Wight. These values corresponds with those of (Holz and Gibbs, 1956) for soils with 'High' degree of expansion and 'High-Very High' classification based on (Chen, 1975) as well as Very High' based on the IS 1498 (1970) (Table 2). The Barton Clay of the Isle of Wight (Sample A) also has the lowest plasticity index with Meduim plasticity (Fig. 5).Sample A obtained from the Isle of Wight is also associated with the lowest percentage moisture content value of 17.1 compared to the Samples B,C and D obtained at the Barton-on -Sea.The percentage shrinkage limit obtained for the Barton Clay indicated values ranging from 7.14-14.2 which corresponds to the 'Medium' classsification based on Holtz and Gibbs, (1956).

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