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CAUSES OF FOUNDATION SETTLEMENT AT BARNAWA COMPLEX, KADUNA

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Abstract: This research present results of laboratory investigation into the cause of settlement of foundation structure, at Barnawa Complex Kaduna. Soil samples were collected from four trial pits located at each side of the building (approach view, rare view and the side views). The soils collected were used to determine the behaviour of the soil present in the site so as to access the suitability of the soil to carry the imposed load. Both disturbed and undisturbed soil samples were collected for visual examination, laboratory testing and classification. The soil samples were subjected to Natural moisture content test, Particle size analysis, Atterberg limit, Compaction, CBR, Specific gravity, Shear box and Consolidation test, and the values obtained from the analysis are between 5.26%-19.16%, 18.50%-27%, MDD is 1.89g/cm^3-2.16g/cm^3 & OMC 11.2%-13.00%, 2.32%-34.58%, 2.51-2.65, C is 27KN/m^2-65.527KN/m^2&Φ is 11°-28°, 1.282 - 6.239m^2/year & 23.00X10^{-3} -99.00X10^{-3} m^2/KN respectively. Bearing capacity ranges between 465.92-2125.44 while safe bearing capacity is between 310.6 -1416.96 and the total settlement is 114.4mm. The result shows that the natural moisture content of the soil increases with increase in water table. From visual inspection during rainy season the site experiences rise in water table beyond reasonable doubt causing the reduction in the strength of the soil which made the building to experience excessive settlement.

Keywords: Foundation Structure; Bearing Capacity; Total Settlement; Consolidation;

INTRODUCTION

Foundation Settlement is the downward movement of a building (building components) to a point below its original position. Foundation settlement is usually the result of the shifting or compaction of the underlying soil, often due to construction on non-virgin (previously disturbed) soil or backfill or changes in soil conditions and moisture content. Most structures experience some degree of settlement within the first few years after construction; however, in most cases this movement is not structurally significant. Settlement cracks most often develop in the foundation or house slab, masonryveneer, ceilings and walls. Small or hairline cracks are often due to minor settlement or thermal movement (expansion and contraction) or as a result of changes in the content of construction materials, rather than significant foundation movement. Cyclic or seasonal movement may or may not represent a significant concern. In severe cases of foundation movement, operational problems with windows and doors may become apparent. Plumbing lines or mechanical equipment can also be affected. Although every situation is different, a crack is generally considered to be of a structural nature when it approaches or exceeds one-quarter inch in width. Smaller cracks may also represent a concern, particularly if there are multiple cracks; however they may be shrinkage cracks, which rarely warrant concern. On the other hand, new or enlarging cracks in an existing structure are more likely an indication of a potentially serious structural issue.

The effects of settlement are often more noticeable and possibly of greater concern in a house with a full concrete slab foundation or masonry veneer construction. Reinforced slab construction allows for limited movement of the slab without damage. Masonry or masonry veneer walls supported by a slab may not be capable of the same range of movement and can crack even without evidence of foundation movement. Improper construction methods or design deficiencies, alone or in conjunction with other conditions, account for many forms of foundation movement. Building on soil with voids or on a fill soil that has not been properly compacted will almost always result in foundation movement. Many cases of settlement are caused by a contractor over-excavating for the foundation footing and then improper backfilling. Settlement that occurs strictly due to normal (or slight) soil compaction generally reaches a point of stability. This explains why in some cases even what is considered a substantial crack might not necessarily be indicative of an on-going or future concern. On the other hand, if the soil the house is built on contains material (organic or man-made), which contains voids or is subject to on-going deterioration, settlement is likely to occur at some point in the future, and will continue until full compaction is reached.

Less frequently, unpredictable and generally more substantial settlement occurs due to mining operations, collapse of limestone caverns, frost heave (in northern climates), and similar phenomena. Settlement of the soil over a large area is called subsidence. It is due to the compaction of subsurface soil layers, primarily sand and clay. It is usually caused by a subterranean withdrawal of water (and oil and gas) from an underground aquifer. Since it occurs over a broad area and at a relatively slow rate, its effect is long-term. With expansive clay soils, there is also a concern that foundation movement may not just appear as settlement but also as upheaval. Clay soil can cyclically shrink or swell with changes in soil moisture levels. This in turn causes cyclic foundation movement and an increased chance of significant damage occurring to the foundation or other components of the house.

Homes built in areas with expansive clays need continual monitoring and maintenance of soil moisture to ensure relative uniformity around the perimeter of a house. The lack of a ground cover, uneven lawn watering practices, changes in subsurface water level, and other factors can lead to uneven drying out of the soil. If this happens, unless the foundation was designed specifically for such conditions, settlement will occur. Conversely, if the soil becomes saturated and swells, upheaval of the foundation can occur. This may be due to a shift from a period of dry to wet weather, over-watering of foundation plantings, or plumbing leaks. Foundation concerns need to be evaluated by an engineer or other qualified specialist. In some cases, long-term monitoring, soils studies, and borings may be required to determine the cause and necessary corrective measures.

Causes of Foundation Settlement

There are two basic causes of foundation settlement. The first type of settlement is directly caused by the weight of the structure. For example, the weight of a building may cause compression of an underlying sand deposit or consolidation of an underlying clay layer. Often the settlement analysis is based on the actual dead load of the structure. The dead load is defined as the structural weight due to members like beams, columns, floors, roofs, and other fixed members. The dead load does not include non-structural items (Live loads) that are defined as the weight of non-structural members, such as furniture, occupants, inventory, and snow. Live loads can also result in settlement of the structure. For example, if the proposed structure is a library, then the actual weight of the books (a live load) should be included in the settlement analyses. Likewise, for a proposed warehouse, it may be appropriate to include the actual weight of anticipated stored items in the settlement analyses. In other projects where the live loads represent a significant part of the loading, such as large electrical transmission towers that will be subjected to wind loads, the live load (wind) may also be included in the settlement analysis. Considerable experience and judgment are required to determine the load that is to be used in the settlement analyses.

Secondly, settlement of a building is caused by secondary influence, which may develop at a time long after completion of the structure. This type of settlement is not directly caused by the weight of the structure. For example, the foundation may settle as water infiltrates the ground and cause unstable soils (i.e., collapsible soil) to collapse. The foundation may also settle due to yielding of adjacent excavations or the collapse of limestone cavities or under-ground mines and tunnels. Other causes of settlement that would be included in this category are natural disasters, such as settlement caused by earthquakes or undermining of the foundation from floods; subsidence usually defined as a sinking down of a large area of the ground surface. Subsidence could be caused by the extraction of oil or groundwater that leads to a compression of the underlying porous soil or rock structure.
Other causes of foundation settlement include;

- Weak Bearing Soils
- Poor Compaction
- Changes in Moisture Content
- Maturing Trees and Vegetation
- Soil Consolidation

Identifiers of foundation subsidence/settlement:

- Diagonal cracking of walls at weak points, such as heads of doors, windows and general openings.
- Cracks that appear suddenly, particularly after long dry or wet spells and that appear to be wider at the top of the crack than at the bottom.
- Wall paper or lining that appears to be 'rippling' or bulging and there does not appear to be any water damage.
- Windows and doors that suddenly begin to 'stick' or can't close properly. (Although this may be due to movement of the construction materials such as the

swelling of
timbers).

In order to determine the causes of foundation settlement in the study area, investigation were carried out on the soil and foundation conditions, so as to check the pressured soil condition, information on foundation behaviour, groundwater condition and engineering properties of the soil. The study was limited to various soil tests and other visual investigation into the causes of settlement in building foundation at Barnawa complex, Kaduna (residential building with excessive cracks due to settlement). The following objectives were considered;

- To investigate into the cause of settlement in foundation (sub – soil investigation)
- To know the engineering properties the soil in the area
- To provide remedies to the problem
- To provide possible preventive measures on how to prevent further occurrences.

Settlement of Foundation

Settlement is defined as the vertical or downward movement of a soil or structure it supports resulting from reduction in the void of underlying strata consequent of the pore water pressure dissipation. Settlement in a structure refers to the distortion or disruption of parts of a building due to:

- Unequal compression of its foundation
- Shrinkage, such as that which occurs in timber framed building as the frame adjusts its moisture content.
- Undue loads being applied to the building after it initial construction (Cull, 2006).

The time calculated at the laboratory at 90% consolidation can be simulated by mathematical relations based on Terzaghi one dimensional consolidation theory to predict the time a structure erected at the site would attain full settlement resulting from the overburden. This would fully inform the engineer on how to design the foundation and more so the rate of erection such that full settlement should have been accomplished at the end of the construction period.

The simulating formula for the site condition is given by;

$$\frac{T1}{H1^2} = \frac{ts}{HS^2} \text{ or } t_s = \left[\frac{HS^2}{H1}\right] T1$$

Where:
t_s = time for 90% consolidation at the site (in minutes)
t_l= time for 90% consolidation in the laboratory
Hs = drainage path of the site stratum
H_l= drainage path of sample

Settlement can be in the form of uniform movement of the foundation or it could be differential because a homogeneous soil mass really exists under actual structure the most predominant problem is the one of differential settlement.
Theoretically if the structure settles uniformly as a whole regardless how large the settlement is no change will be in connection of house hold utility and convenience e.g. water pipes and sewage pipes.

Uniform Settlement
This is when the structure settles equally across the entire structure at an equal rate. This is hard to detect since the stress is equally distributed. This type of foundation settlement is rare.

Differential Settlement
This is when a structure settles at different rates causing only part of the structure to settle. This is typical in most foundation repair in most foundation repair cases. The signs usually show as cracks in bricks, cracked blocks foundations, interior drywall cracks, and windows and doors that are hard to open and close. Because the settlement is varied, it can change how the load of the structure is distributed.

Causes of Differential Settlement include:

i. Variation in soil strata
ii. Variation in foundation loading
iii. Large loaded areas on flexible foundation.
iv. Differences in time of construction of adjacent part of the structure such as when extending in existing building.
v. Variations in the conditions of the site with time.

Prevention of Differential Settlement

1. Provision of deep basement to reduce the net bearing pressure of the soil.
2. Provision of raft foundation

3. Transferring the foundation to a deeper as lesser compressive stratum using pile.

It should be noted that the highest percentage of failures (settlement) in foundation are due to improper soil composition rather than construction technique.

Types of Settlement

i. Immediate settlement
ii. Consolidation settlement

Immediate Settlement

This is also called distortion or contact settlement and occurs immediately on application of a foundation load. Such immediate settlement is the expulsion of gases and the rearrangement soil particles. In the case of settlement in saturated soil, immediate settlement is the results of vertical soil compression before any change in volume occurs.

Immediate Settlement on Cohesion Less Soil (Sand)

In the case of the immediate as well as the primary settlement of cohesion less soil because of their highly permeability, the immediate settlement, Si is given by:

$$\text{Si} = \frac{H}{C2}\log e\,\partial o + \frac{V\partial}{\partial o}$$

Where:

H = thickness of the layer getting compressed

∂o = effective over burden pressure at the centre of the layer before any excavation application.

$V\partial$ = vertical stress increment at the centre of the layer.

Mv = compressibility coefficient by

$$\text{Mv}=\frac{1.5\,Cr}{\partial o}$$

Cr = being the state come resistance in (KN/M^2)

Immediate Settlement of Cohesive Soil (Clay)

In saturated clay which pressures are induced, the soil gets deform with usually no volume change. And due to low permeability of the clay little water is squeezed out of the void.

The vertical deformation due to the change in shape is the immediate settlement which is given by:

$$\text{Si}= \text{QB}\left(\frac{1-\mu 2}{ES}\right)I_f$$

Where:

Si = immediate settlement at the corner of a rectangular flexible foundation of size LXB.
B = width of the foundation.
Q = uniform pressure of the foundation
Es = modulus of elasticity of the soil beneath the foundation
μ = poison ratio of the soil
I_f = Influences valve which is independent on L/B.

The values of I_f are tabulated below.

Table 2.7.1

L/B	1	2	3	4	5
1_f	0.56	0.76	0.88	0.96	1.00

The influence values of settlement of a corner of a rectangular foundation of Si, L x B (after Terzaghi 1943)

Consolidation Settlement

According to Terzaghi(1919) consolidation is any process which involves a decrease in water content of saturated soil without replacement of water by air. The settlement of foundation of structures where the beds of cohesiveness and cohesive soil (clay and sand) sometimes buried deeply beneath stronger and less compressible materials may take place slowly and may reach large magnitudes because of the time lag between the end of construction and appearance of craving, such settlement were considered to be mysterious origin.

The first successful effort to explain the phenomenon on a scientific basis was made by Terzghi in 1919. Terzaghi studies dealt with the amount and rate of settlement originating in a large of sand and clay preventing them from experiencing lateral displacements and capable of expelling water downward in the particles landed to squeezed together in case clay. The concept of consolidation becomes necessary. Consolidation is a time dependant compression of soil mass bringing about an elector plastic deformation ultimately resulting in a permanent reduction in void ratio due to an increase in stress. The stress should be uniform of a load. If for example a load is applied to a slanted compressible soil mass, the load is usually carried initially by the water in the pores because water is relatively incompressible when results in the water due to the load is called hydrostatic pressure. If the water is drawn from the soil pores, the hydrostatic pressure and its gradient gradually decrease and the load increment is shifted to the soil. The transference of load is accompanied by a change in the volume of soil mass and to the volume of water drained this process called consolidation Fang (2013).

There are two major characteristics of consolidation.

a. Compression index Cc and
b. Coefficient of consolidation Cv.

Compression Index Cc: This relates to how much consolidation or settlement will take place.
Coefficient of consolidation Cv: This relates to how long it will take for an amount of consolidation to take place. Consolidation parameters can be obtained from an Oedometer test.

Types of Consolidation

1. Primary Consolidation

The increase in vertical pressure is principally due to the squeezing out of water from the void in the mass, accompanied by a transfer of load from the soil water to the soil solids is called primary consolidation.
Determination of primary consolidation method assumes consolidation occurs in only one-dimension. Laboratory data is used to construct a plot of strain or void ratio versus effective stress where the effective stress axis is on a logarithmic scale. The plot is the compression index or recompression index. The equation for the consolidation settlement of a normally consolidationsoil can be determined to be.

$$\delta_c = \frac{Cr}{1+eo} + \text{Hlog}\left(\frac{\delta zp}{\sigma z0}\right) + \frac{Cc}{1+eo}\text{Hlog}\left(\frac{\delta z1}{\sigma zp}\right)$$

Where:

C_v= is the settlement due to consolidation.
Cc= compression index.
e_o= initial void ratio.
H = height of the compressible soil.
σ_{z1}= final vertical stress.
σ_{z0}= initial vertical stress.

Cc can be replaced by Cr (the recompression index) for use in under consolidation soils where the final effective stress is less than the pre-consolidation stress; the two equations must be used in combination to

model both the recompression portion and the virgin compression portion of the consolidation processes, as follows.
Where:
(σ_{zp}) is the pre-consolidation stress of the soil.

2. Secondary Consolidation

Secondary consolidation is the compression of soil that takes place after primary consolidation. Even after the reduction of hydrostatics pressure some compression of soil takes at slow rate. This is known as secondary compression. Secondary compression is caused by creep, viscous behaviour of clay-water system, compression of organic matter and other processes. In sand, settlement caused by secondary compression is negligible, but in peat, it is very significant. Due to the secondary compression some of the highly viscous water between the points of contact is forced out.
Determination of secondary consolidation can be given by;

$$\frac{H_O}{1+eo} \text{ Ca log } \left(\frac{t}{t90}\right)$$

Where:
H_o= height of the consolidating medium
e_o= initial void ratio.
Ca = secondary compression index
t =length of time after consolidation considered
t_{90}=length of time for achieving 90% consolidation.
Skempton and Bjerrumsummarize that:
Immediate Settlement=0.1 Pc
Final Settlement =1.1 Pc
Pc=total consolidation settlement.

Bearing Capacity

Foundation serves as the lowest part of the structure which is in contact with soil and transmits load to it. Footing is therefore the portion of the foundation of the structure, transmits load directly to the foundation soil.
Bearing capacity is the load carrying capacity of foundation soil or rock which enables it to bear and transmit loads from a structure. The subject of bearing capacity is perhaps the most important of all the aspects of geo-technical engineering. Loads from buildings are transmitted to the foundation by column, by load bearing walls or by such other load bearing component of structures. A scientific treatment of the subject of

bearing capacity is necessary to enable one to understand the factors upon on which it depends as follows:

Ultimate bearing capacity: Maximum pressure which a foundation can withstand without the occurrence of shear failure of the foundation.

Gross bearing capacity: The bearing capacity inclusive of the pressure exerted by the weight of the soil standing on the foundation, or the "surcharge" pressure, as it is sometime called.

Net bearing capacity: Gross bearing capacity minus the original over burden pressure or surcharge pressure at the foundation level.

Safe bearing capacity: Ultimate bearing capacity divided by the factor of safety. The factor of safety in foundation may range from 2 to 5, depending upon the importance of the structure and the soil profile at the site.

Allowable bearing pressure: The maximum allowable net loading intensity on the soil at which the soil neither fails in shears nor undergoes excessive or intolerable settlement, detrimental to the structure.

Factor affecting Bearing Capacity

Bearing capacity is governed by a number of important ones which affect bearing capacity;

i. Nature of soil and its physical and engineering properties.
ii. Nature of the foundation and other details such as the size, shape, depth below the ground surface and rigidity of the structure.
iii. Total and differential settlements that the structure can withstand without functional failure.
iv. Location of the ground water table relative to the level of the foundation.
v. Initial stresses, if any.

Methodology

The methodology used for the test includes the use of disturbed and undisturbed soil sample. The disturbed soil sample are collected at certain depths using the disturbed method of soil collection while the undisturbed soil samples are collected using the undisturbed method.

Disturbed soil: Disturbed soil is defined as soil that has been remoulded during the sampling process. For example, soil obtained from driven samplers, such as the Standard Penetration Test spilt spoon sampler, or chunks of intact soil brought to the surface in an auger bucket (i.e., bulk samples), are considered disturbed soil. Disturbed soil can be used for numerous types of laboratory tests.

Undisturbed soil: It should be recognized that no soil sample can be taken from the ground in a perfectly undisturbed state. However, this terminology has been applied to those soil samples taken by certain sampling methods. Undisturbed samples are often defined as those samples obtained by slowly pushing thin walled tubes, having sharp cutting ends and tip relief, into the soil.

Laboratory Works

Laboratory works for settlement investigation includes:

a. Identification and classification of soil sample from cracked building
b. Engineering properties of all the soil samples collected.

Some of the relevant tests performed on the collected soil samples are:

i. Moisture content test
ii. Sieve analysis
iii. Atterberg limit test
   a. Liquid limit test
   b. Plastic limit test
c. Shrinkage limit
iv. Proctor compaction test
v. Specific gravity test
vi. Shear box test
vii. Consolidation test
viii. California bearing ratio (CBR)

The definition, method and procedures adopted for the above test are in accordance to BS 1377.

Results and Discussion

Moisture Content Test

Weight of wet soil = (Weight of can+ wet soil) – (Weight of empty can)

Weight of dry soil =(Weight of can+ dry soil)–(Weight of empty can)

Weight of moisture = (Weight of wet soil) – (Weight of dry soil)

Moisture content (%) = $\frac{weight\ of\ moisture}{weight\ of\ dry\ soil}$ X 100

Sieve Analysis

Generally, the results of average values of the grain size distribution obtained are approximately are silt clays fine, Sands with high plasticity, sandy clays, clayey sandy.

From the sieve analysis result has shown that the soil mostly composed of brown sandy silt with clay content ranging from coarse fine-medium sand, but the percentage of clay and silt content is higher than that of sandy particles, well graded and have fairly representative sample of the grains, because the coefficient of uniformly and coefficient of curvature falls within the specified range.

Experiments shows that cohesive or cohesion less behaviour of soil depends on the size of particles and clay-silt content in the soil, permeability and capillary are related to effective particle diameter.

Atterberg Limit Test

The liquid limits (LL) as obtained from the plotted graph together with the plastic limit (PL), plasticity index (PI) and shrinkage limits (SL) computed corresponding to various depths are shown.
Where:
Plasticity index (PI) = LL – PL

Shrinkage limit = $\frac{L1 - L2}{L1}\ X\ 100$

The general liquidity of the soil sample obtained from the site is less than 28% and of low plasticity. The results of the liquid limit are within the range of 18.50 to 27%; and the average liquid limit is 26.33%.Therefore it is clear that the percentage of moisture content is higher than the natural moisture content. And this is the liquid limit moisture at which the soil tends to flow which indicates that the shearing resistance is destroyed.
Finally, results from the Atterberg Limit Test shows that liquid limit value is greater than the natural moisture content present on the site under investigation, therefore excessive water was not found on the site.

Compaction Test

Volume of water added (subsequently) = 3% of weight of soil

Volume of mould = $\frac{\pi\, d^2 H}{4} = \frac{\pi\, X\, (10)^2 X\, 12}{4}$ = 942.6cm^3

Dry density determination

Weight of bulk sample = (Weight of mould+ bulk sample) – (Weight of empty mould).

Bulk density ρ = $\frac{Mass}{Volume}$

Dry density =$\frac{bulk\ density\ (\rho)}{1+W}$ where: ρ = bulk density in (g/cm^3)

W = moisture content in (%)

Void ratio (e) = Moisture content (Mc) X Specific gravity (Gs)

∴e = M_c X G_s

Specific Gravity (G_s) Test

Specific gravity (G_s) = $\frac{M2 - M1}{(M4 - M1) - (M3 - M2)}$

Trial Pit 1 @ 1m

Specific gravity (G_s) = $\frac{51.40 - 29.80}{(81.70 - 29.80) - (95.10 - 51.40)}$ = 2.63g

California Bearing Ratio (CBR)Test

Calculation for CBR Value:

CBR penetration = $\frac{Apllied\ load\ X\ Calibrating\ factor}{P1}$ X 100

Where:

P_1 = standard crush value

Calibrating factor = 0.0301

Using terzaghi's equation to design for the worst condition

$q_u = CN_c + \gamma D(N_q - 1) + 0.5\gamma B\, N_\gamma$

Table 4.9 showing various bearing capacity and safe bearing capacity

S/N	Sample	Depth (m)	Description	Ø	N_c	C	Nq	Nɤ	ɣ	B.C	Safe B.C.
1.	TP1	1.0	Redish brown sandy Clay	21	18.92	27	8.26	4.31	16.69	667.98	445.32

2.		1.5	Brown redish sandyClay	20	17.69	32.1	7.44	3.64	16.76	760.25	506.83
3.		2.0	Grey redish clay	28	31.61	45.5	17.81	3.70	16.98	2125.44	1416.96
4.	TP2	1.0	Redish brown clay	28	31.61	28	17.81	13.70	18.28	1317.58	878.39
5.		1.5	Redish brown silt	17	14.6	45.1	5.45	2.18	17.26	792.48	528.32
6.		2.0	Brown redish late rite	23	21.75	50.2	10.23	6.00	18.09	1480.06	986.71
7.	TP3	1.0	Redish brown silt	13	11.41	35.2	3.63	1.04	20.41	465.92	310.61
8.		1.5	Redish brown laterite	14	12.11	45.1	4.02	1.26	18.96	643.99	429.33
9.		2.0	Grayish brown lateritic clay	21	18.92	48.7	8.26	4.31	19.26	1242.56	828.37
10.	TP4	1.0	Glayish clay	11	10.16	65.5	2.98	0.69	16.09	702.89	468.59
11.		1.5	GrayishBrowni clay	21	18.92	54.7	8.26	4.31	15.88	1242.08	828.05
12.		2.0	Brownish organic silty clay	18	15.12	60	6.04	2.59	15.93	1088.40	725.60

The result shows that trial 3 at 1.0m has the lowest bearing capacity and trial pit 1 at 2.0m has the highest bearing capacity. The foundation the settled building was found at a depth of 1.0m below the ground surface which has a lower bearing capacity compared to other depth.

Shear Box Test

Normal stress = $\frac{Applied\ load\ (kg)\ X\ 9.81\ X\ 10{-}3\ (KN)}{Area\ of\ mould\ (m2)}$

Shear stress = $\frac{Dial\ gauge\ reading\ X\ Calibrating\ factor\ (KN/Div)}{Area\ of\ mould\ (m2)}$

Where:

Bulk density (Ɣ) = $\frac{Mass}{Volume}$

The plotted graph using the shear stress against the normal stress, the values of the apparent cohesion(C) and angle of internal friction(Ø) are shown. See Appendix for the other calculations.
From the direct shear box test conducted for the undisturbed soil used, the maximum shearing resistance due to cohesion of the soil falls within the range of 27KN/m^2 to 65.5KN/m^2, and the angle of internal friction is within the range of 11^0 to 28^0. The average maximum shearing resistance due to cohesion is 65.5KN/m^2, however the higher the shearing resistance the more suitable the soil become which will subsequently increase the stability of the foundation.

If the shear resistance due is too small, there is every likelihood that foundation will fail, it is necessary to provide remedy for the failure by introduction of a retaining wall to support the earth round the foundations.

Consolidation test

Using square root of time method the reading obtained is plotted as shown in the consolidation graph. The compression dial reading was plotted on the y-axis against the square roof of time on the x-axis.
The coefficient of consolidation was calculated from the graph using the below formula.

$$CV = \frac{0.848d2mm/sec}{T90}$$

Where:
CV = Coefficient of consolidation.
D = Diameter of the sample.
t_{90} = The time obtained from the intersection of tangential line drawn has indicated on
the curve.
The tables below shows the necessary computed values at various depth

Table 4:8 Consolidation Test Result

Trial Pit No	Depth [m]	C_V [m^2/year]	M_V x10^{-3} [m^2/KN]	K x10^{-7} [mm/sec]	P_c x10^{-4}[m]
Tp1	1.00	2.448	2.600	1.721	2.000
	1.50	1.291	2.900	0.985	3.000
	2.00	6.239	2.300	5.081	2.000

Tp2	1.00	3.760	9.900	1.618	9.000
	1.50	2.286	8.900	1.018	8.000
	2.00	4.173	6.500	1.963	6.000
Tp3	1.00	1.539	4.300	0.882	4.000
	1.50	1.282	3.500	0.802	3.000
	2.00	3.193	2.800	2.115	3.000
Tp4	1.00	1.052	5.800	0.329	5.000
	1.50	3.150	4.000	1.117	4.000
	2.00	1.153	3.500	0.437	3.000

The coefficient of consolidation and coefficient of permeability ranges i.e. (Cv and Mv) are estimated to be 1.282 to 6.239m^2/year and 23.00X$10^{-2}$to 99.00X$10^{-2}$$m^2$/KN. The maximum consolidation settlement from the plotted graph is 0.90mm.

CONCLUSION

The necessary laboratory tests performed on the soil samples collected from the site under investigation which is mostly reddish and brownish clay with some sandy particles plastic in nature, the results revealed that the bearing capacity ranges from 465.92 – 2125.44KN/m^2. While the safe bearing capacity ranges from 310.61-1416KN/m^2. The bearing capacity of pits 1 & 2 increased in respect to its depth. Since the bearing capacity is greater than the safe bearing capacity, it can be said that the soil has adequate capacity to carry the imposed structure but settled due to lack of adequate foundation type and depth.

Consolidation test revealed that settlement due to consolidation was found to be 52.0mm, immediate settlement is 5.2mm, primary consolidation is 57.2mm and total settlement is 114.4mm which is within the limits of Skempton and McDonald tolerable settlement for building under clay soil. Kempton and Bjerrum suggested that clay with very low compressibility usually have the coefficient of compressibility Mv less than 0.05 and based on the calculation Mv was found to be 0.0544 > 0.05, which means the soil has a very high compressibility which aid settlement.

Compaction test revealed that maximum shear strength will be achieve based on the dry density and optimum moisture content obtained, because maximum shear strength usually achieved at lower moisture content according to BS-1377.

Also, result from sieve analysis i.e. particle size distribution shows that the soils are majorly clayey sand, silty sand, silt and lean clay. Furthermore, result from Atterberg limit shows that the liquid limit values obtained is greater than the natural moisture content present on the site.However, the natural moisture content of the soil increases with increase in water table. More so, using visual inspection and the result obtained, during rainy season the site experiences rise in water table beyond reasonable doubt causing the building to experience excessive settlement in conclusion.

RECOMMENDATIONS

Settlement of soil is a natural phenomenon and may be considered to be unavoidable. However, a few remedial measures are possible against harmful settlement. The following remedial measures should be taken to prevent settlement from this and other structures too, mostly before the construction.

1. The foundation should be taken to deeper strata below the zone of subsidence.
2. If possible underpinning should be provided.
3. Removal of soft soil strata, consistent with economy.
4. The use of properly designed and constructed pile foundations.
5. Provision for lateral restraint against lateral expulsion of soil mass from underneath the footing of a foundation.
6. Building slowly on cohesive soils to avoid lateral expansion of a soil mass and to give time for the pore water to be expelled by the surcharge load.
7. Reduction of contact pressure on the soil; more appropriately, proper adjustment between pressure, shape and size of the foundation in order to attain uniform settlements underneath the structure.
8. Preconsolidation of a building site long enough for the expected load, depending upon the tolerable settlements; alternatively, any other method of soil stabilization.

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APPENDIX

SUMMARY OF LABORATORY TEST RESULTS

Location (no. 7 Barnawa complex kaduna)	Depth (m)	NMC		GS	MDD (kg/m3)	OMC (%)	CBR (%)	LL (%)	PL (%)	LI (%)	L.S (%)	SIEVE ANALYSIS			SHEAR BOX		Classification	
		DISTURBED	UNDISTURB.									No. 7 2.36mm	No. 36 0.425mm	No. 200 0.07mm	C	ø	SYMBOL	NAME
TP 1 @	1.00	7.43	8.19	2.63	2.05	11.50	2.32	21.60	9.05	12.55	4.29	79.32	45.00	26.02	27.00	20.05	SC	Clayey sand
	1.50	8.86	10.76	2.61	1.89	11.20	5.25	24.50	6.71	17.79	5.10	96.26	52.64	30.52	32.10	20.00	SC	Clayey sand
	2.00	10.11	12.59	2.65	2.05	13.00	6.92	25.00	8.05	16.95	5.08	98.92	61.55	28.10	45.50	28.00	SM	Silty sand
TP 2 @	1.00	10.91	14.50	2.58	2.03	12.00	5.00	18.50	9.00	9.50	6.43	96.36	78.16	70.80	28.00	28.00	CL	Lean clay
	1.50	12.07	15.32	2.60	2.05	12.5	7.22	25.20	10.17	15.03	6.84	96.82	75.10	83.96	45.10	17.00	ML	Silty
	2.00	14.03	18.01	2.57	2.16	12.4	9.16	24.80	9.76	15.04	7.21	96.22	73.68	62.68	50.20	23.00	SM	Silty sand
TP 3 @	1.00	12.52	15.70	2.59	1.97	12.30	21.23	21.80	10.39	11.41	14.29	95.10	87.58	83.96	35.20	12.50	ML	Silty
	1.50	14.95	16.65	2.64	2.02	12.00	24.71	22.30	9.53	12.77	15.36	95.90	80.64	69.56	45.10	13.50	CL	Lean clay
	2.00	16.25	19.16	2.65	2.06	11.90	34.58	26.80	10.82	15.98	15.14	96.42	78.50	66.70	48.70	21.00	ML	Silty clay
TP 4 @	1.00	4.25	5.78	2.51	1.94	13.40	10.48	24.90	13.86	11.04	7.14	96.44	85.38	78.00	65.50	11.00	CL	Lean clay
	1.50	5.26	6.69	2.58	2.16	11.20	15.95	23.00	14.29	8.71	6.64	96.36	80.92	70.70	54.70	21.00	CL	Lean clay
	2.00	7.42	8.39	2.55	2.14	12.00	16.50	27.00	13.48	13.52	8.10	95.50	78.28	63.60	60.00	18.00	SM	Silty sand

Settlement Calculation (mm)

Trial pit	PC	Si	Sf	ST
1	0.007	0.0007	0.007 7	0.0154
2	0.023	0.0023	0.025 3	0.0506
3	0.010	0.0010	0.011 0	0.0220
4	0.012	0.0012	0.013 2	0.0264
Total	0.052	0.0052	0.057 2	0.1144
in (m)				114.40

	Bearing capacity (KN/M^2)	Safe B. C. (KN/M^2)	Trial pit (m)	Mv (m^2/KN)
	667.98	445.32	1.0	0.0026
	760.25	506.83	1.5	0.0029
	2125.44	1416.96	2.0	0.0023
	1317.58	878.39	1.0	0.0099
	792.48	528.32	1.5	0.0089
	1480.06	986.71	2.0	0.0065
	465.92	310.61	1.0	0.0043
	643.99	429.33	1.5	0.0035
	1242.56	828.37	2.0	0.0028
	702.89	468.59	1.0	0.0058
	1242.08	828.05	1.5	0.004
	1088.40	725.60	2.0	0.0035
			Average MV	0.0544
Total	12529.63	8353.09		
Average	1044.14	696.09		

Reference to this paper should be made as follows: Salihu Andaa Yunusa[1], et al, (2017), Causes of Foundation Settlement at Barnawa Complex, Kaduna. *J. of Sciences and Multidisciplinary Research,* Vol. 9, No. 4, Pp. 39-62

TABLE 1 Soil Classification Chart

Criteria for Assigning Group Symbols and Group Names Using Laboratory Tests[A]				Soil Classification: Group Symbol	Soil Classification: Group Name[B]
COARSE-GRAINED SOILS	Gravels	Clean Gravels	$Cu \geq 4$ and $1 \leq Cc \leq 3^C$	GW	Well-graded gravel[D]
More than 50 % retained on No. 200 sieve	More than 50 % of coarse fraction retained on No. 4 sieve	Less than 5 % fines[E]	$Cu < 4$ and/or $1 > Cc > 3^C$	GP	Poorly graded gravel[D]
		Gravels with Fines	Fines classify as ML or MH	GM	Silty gravel[D,F,G]
		More than 12 % fines[E]	Fines classify as CL or CH	,urule;1>GC	Clayey gravel[D,F,G]
	Sands	Clean Sands	$Cu \geq 6$ and $1 \leq Cc \leq 3^C$	SW	Well-graded sand[H]
	50 % or more of coarse	Less than 5 % fines[I]	$Cu < 6$ and/or $1 > Cc > 3^C$	SP	Poorly graded sand[H]
	fraction passes No. 4 sieve	Sands with Fines	Fines classify as ML or MH	SM	Silty sand[F,G,H]
		More than 12 % fines[I]	Fines classify as CL or CH	SC	Clayey sand[F,G,H]
FINE-GRAINED SOILS	Silts and Clays	inorganic	$PI > 7$ and plots on or above "A" line[J]	CL	Lean clay[K,L,M]
50 % or more passes the No.	Liquid limit less than 50		$PI < 4$ or plots below "A" line[J]	ML	Silt[K,L,M]
200 seive		organic	Liquid limit – oven dried> < 0.75	OL	Organic clay[K,L,M,N]
			Liquid limit – not dried	OL	Organic silt[K,L,M,O]
	Silts and Clays	inorganic	PI plots on or above "A" line	CH	Fat clay[K,L,M]
	Liquid limit 50 or more		PI plots below "A" line	MH	Elastic silt[K,L,M]
		organic	Liquid limit – oven dried < 0.75	OH	Organic clay[K,L,M,P]
			Liquid limit – not dried		Organic silt[K,L,M,Q]
HIGHLY ORGANIC SOILS	Primarily organic matter, dark in color, and organic odor			PT	Peat