FOUNDATION SOIL CHARACTERISATION FOR A BUILDING WITH MULTIPLE CRACKS AT TARKWA, GHANA

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Authors' contributions

This work was carried out in collaboration between all authors.Author GMT designed the study, managed the literature and wrote the first draft of the manuscriptand effected most of the corrections after the review. Authors FAMand BO did the field sampling, laboratory analyses and statistical plots. Authors FAM and BOorganised the manuscript to journal format with guidance from author GMT and revised the plots after the review. All authors read and approved the final manuscript.

ABSTRACT

Formation of cracks on buildings could be attributed to many factors such as properties of soils, geology, structural defects and climatic conditions. A public building at Tarkwa in the Western Region of Ghana developed cracks that rendered it unsafe and so it was demolished for a new structure to be put in place. Geotechnical investigations were undertaken to ascertain possible contributions of the foundation soils to development of these cracks before it was demolished. Site investigations on test holes and laboratory analyses showed that, the foundation soils were mainly dense silty sand, with average moisture content of 8.9% and specific gravity of 2.7Kg/m^3.These characteristics aretypical of quartz sands. Though the soil at the site where the building was situated was non-plastic, plasticity index (PI) for soils at neighbouring sitesranged from 1.5% to 7.8% at an average of 4.9% and so consolidation immediately after structural loading was negligible and might not result in differential settling. Moisture content was lower than liquid limitas liquidity indices were between -0.326 to -12.653.These soils exhibited minimal liquefaction potential and were free draining.They were of high permeability and therefore could consolidate immediately after being subjected to structural load.Hence the foundation soils played little role in the formation of cracks on the building which was exposed to frequent ground vibration as the building wasclose to a defunct underground mine,heavy vehicular traffic and a railway station; with surface mining activities at a permitted distance.

***Keywords**: Soil Characterisation, Building foundation, Differential settling, Cracks*

1. INTRODUCTION

Building foundations need to be on stable and strong soils to avoid cracks, sinking, or falling. Geotechnical investigations before, during, and after construction are necessary to avoid the formation of cracks on buildings, walls and floors [1]. Cracks can result from external forces such as shrinking and swelling of some clay minerals when subjected to moisture variations, differential foundation movements, and poor compaction of foundation soils and settling from dimensional changes in the masonry work [2]. Formation of cracks on a building could also be attributed to many factors such as structural defects, geotechnical defects and geology [3]. The old public building had cracks before it was pulled down for reconstruction in 2007. According to [4]the cracks on the structure could be attributed to geological structures in the foundation rocks. This paper presents geotechnical evaluation of foundation soils to verify if they contributed to the formation of the cracks on the building.

2. GEOLOGY OF TARKWA

Tarkwaian rocks in the Ashanti belt of Ghana stretch from near Axim in the Western Region to the edge of the Voltaian basin near Agogo in the Ashanti Akim District [5]. The Birimian consists of metamorphosed volcanic rocks and metasedimentary rocks. Initial subdivision by [6] placed the rocks into LowerBirimian made up of metasedimentary rocks while the Upper Birimianmainly comprises of metavolcanic rocks. According to [7]these rocks are contemporaneous and form lateral facies and were intruded by belt granitoids andbasin granitoids into volcanic rocks andmetasedimentary rocks respectively. The Tarkwaian is regarded as younger than the Birimian as the basal rock of the Tarkwaian, which is the Kawere conglomerate, consists of reworked pebbles from the Birimian and so it is made up of sub-rounded closely packed pebbles of Birimianmetavolcanic rocks, metasedimentary rocks, granitoids, carbonates, quartz and other vein minerals and rocks. The Kawere Group is overlain by a palaeoplacer gold bearing banket quartz conglomerate. The Tarkwaian stratigraphy by [8] from the youngest above is as follows:

- Huni Sandstone and DompimPhyllites
- TarkwaPhyllites
- Banket Series
- Kawere Conglomerate

The Banket Series is subdivided into footwall and hanging wall quartzites separated by a sequence of mineralised quartz-pebble conglomerates and pebbly quartzites. The general orientation of pebbles show that fluvial transport was from east and north-east[9]. The Tarkwaian sequence had been subjected to low-grade regional metamorphism of greenschistfacies and according to [10], subjected to five episodes of deformation accompanied by thrust faults and dolerite sills.

3. METHODOLOGY

The site in this study was at the premises of a building which housed public offices at Tarkwa but had structural defects made up of multiple cracks on the walls at various angles, lengths, widths, depths and extent of displacement [4]. The building was close to a market, lorry station and situated ninety-two metres (92 m) north of an old adit with crosscuts. It was a low-rise building with about six offices and toiletry facilities. The building was constructed with sand mixed with cement (sandcrete). The cracks on the walls made the building unsafe for habitation and so it was demolished and reconstructed.

Three test pits were excavated in *in situ* surface soil with a pick axe and shovel to a depth of 1 m each. Samples labelled AD, BS and FS were taken from spots neara mine adit, close to UMaT Basic School and at a site near the building respectively (Figure 1). The purpose of excavation was to visually examine the soil profiles and obtain soil samples for laboratory tests to ascertain physical characteristics of the various layers of soil.

The following laboratory tests were carried out in accordance with BS 1377 [11]:

- Moisture content
- Specific gravity
- Atterberg Limits
- Particle Size Distribution

4. RESULTS AND DISCUSSION

The results of the laboratory tests are presented in Table 1 and distribution curvesare shown in Figure 2.From Table 1, samples from the surface to 0.5 mdepth showed various proportions of silt, gravel and sand. Moisture content varied from 5.42% in sample BS to 9.08% in the sample at the site (FS), clay content varied from a minimum of 0.0 in samples BS and FS but highest in sample AD at 3.0%. Silt is lowest in sample FS (17.8%) and highest (72%) in sample AD; gravel content is minimum (0.4%) in sample AD and highest (28.2%) at the site (sample FS). An intermediate layer between 0.5 -0.7 m depth occurred near the adit which was made up of gravelly, silty sand (gravel - 9.8%, silt - 12.4%, and sand – 78.8%). This layer wasnon-plastic, contained moisture content of 11.45% and specific gravity of 2.64Kg/m^3.

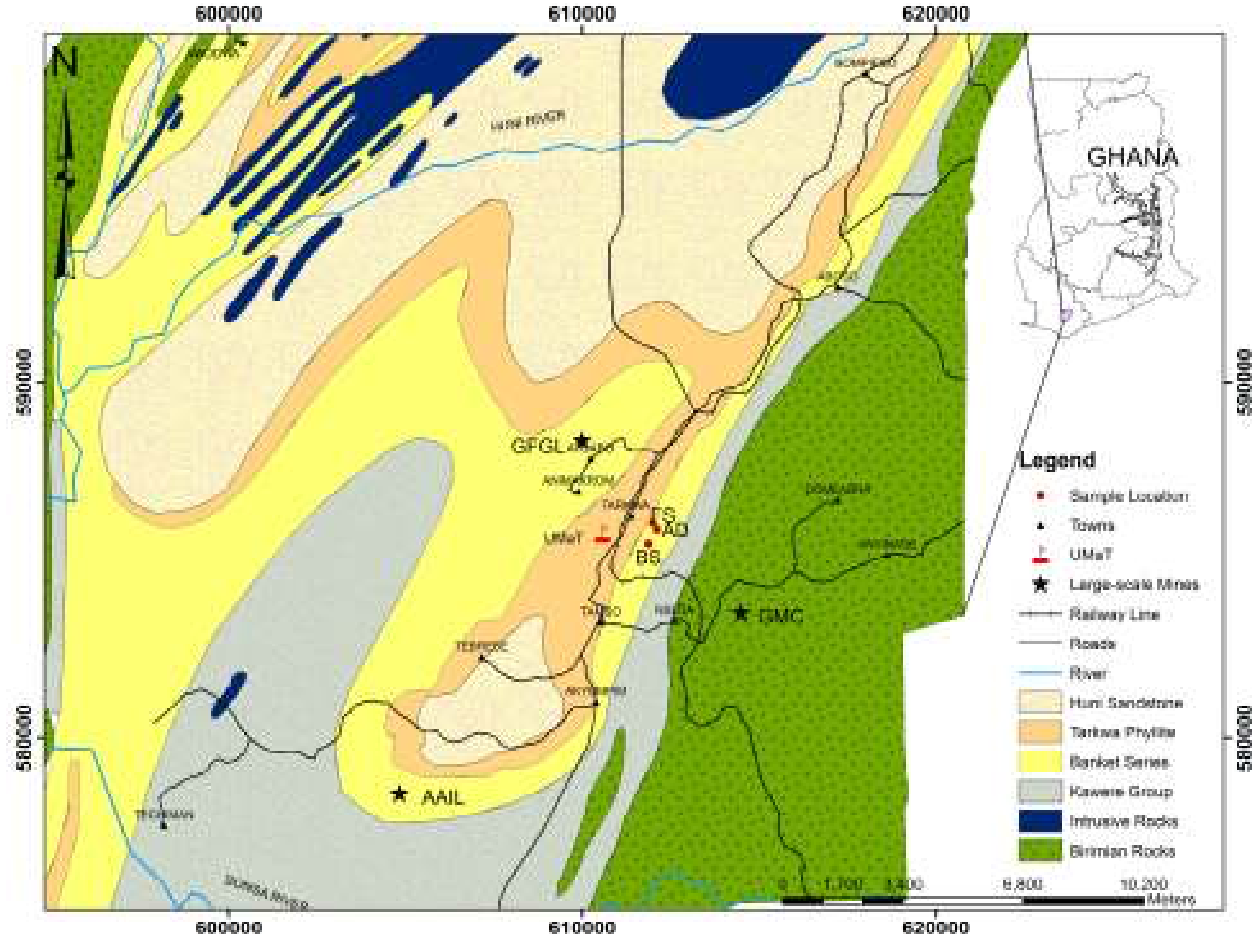

Figure 1: Geological Map of Tarkwa area showing Sample Locations (Modified after [6])

Table 1 Summary of Laboratory Tests on Soils from Tarkwa

Sample Location	Depth (m)	Moisture Content (%)	Specific Gravity(Kg/m^3)	ATTERBERG LIMITS (%)			PARTICLE SIZE ANALYSIS (HYDROMETER) (%)				REMARKS
				LL	PL	PI	Clay (C)	Silt (M)	Sand (S)	Gravel (G)	
AD	0.0 - 0.5	8.85	2.64	20.9	13.1	7.8	3.0	72.0	24.6	0.4	Sandy silt with some clay
	0.5 - 0.7	11.45	2.64	NON-PLASTIC			0.0	12.4	77.8	9.8	Gravelly silty sand
	0.7 – 1.0	14.93	2.64	20.5	16.3	4.2	1.6	12.2	69.2	17.0	Silty gravelly sand with some clay
BS	0.0 - 0.5	5.42	2.68	25.9	24.4	1.5	0.0	24.0	63.6	12.4	Gravelly silty sand
	0.5 – 1.0	6.39	2.68	19.9	13.4	6.5	0.0	24.0	66.0	10.0	Gravelly silty sand
FS	0.0 - 0.5	9.08	2.68	NON-PLASTIC			0.0	17.8	54.0	28.2	Silty gravelly sand
	0.5 – 1.0	6.42	2.68	NON-PLASTIC			0.0	8.0	22.8	69.2	Sandy gravel with some silt

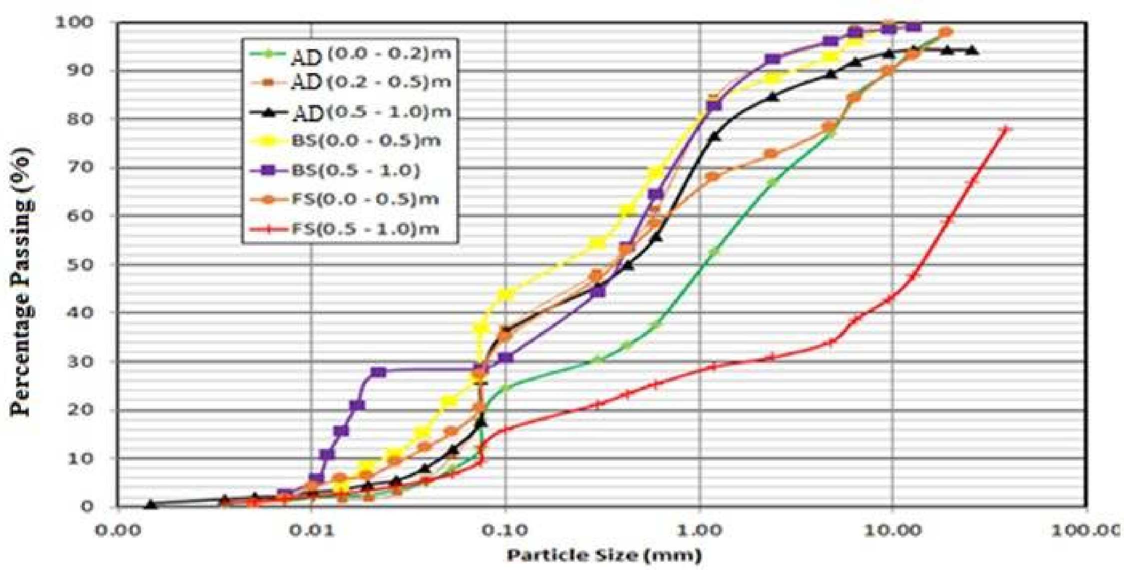

Figure 2: Particle Size Distribution of Soils at the Tarkwa Site

The soil layer up to 1.0 m was made up of various types of soil proportions. The layers were uniform in depth (0.5 – 1.0 m) at the Basic School (BS) and the building site (FS) but at the adit area it was 0.7 -1.0 m. The soils were made up of clay - 0.0 to 3.0% (sample AD); silt - 12.2% (sample AD) to 24.0% (sample BS); sand - 22.8% (sample FS) to 69.2% (sample AD) and gravel - 10.0% (sample BS) to 69.2% (sample FS). The area is underlain by dense silty sand with admixtures of gravel and minor clay. The average moisture content was 8.9% with average specific gravity of 2.7 Kg/m^3; typical of quartz sands. The plasticity index (PI) ranged from 1.5% to 7.8% with an average of 4.9% (Table 1). Figure 3 shows that the soil at the site wasmainly silt and non-plastic.

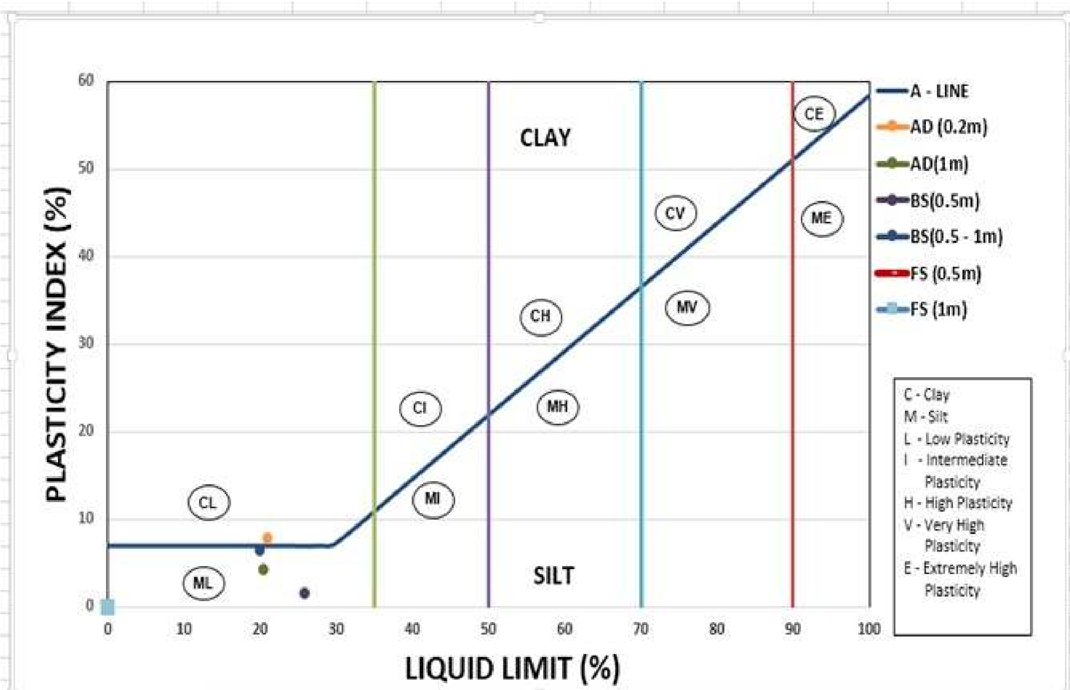

Figure 3: Plasticity Index vs. Liquid Limit of the Soils from Tarkwa Site

Ground vibration caused by mine blast and movement of heavy duty trucks in the building area was likely to subject the soil at the site to liquefaction due to its composition of silty sand with low clay. Liquefaction potential analysis of the foundation soils showed that the moisture content (MC) waslower than liquid limit(LL).Hence *in situ* water content was above the liquid limit. Soils under these conditions are unstable during ground vibrations as the larger the MC with respect to LL, the greater the likelihoodof liquefaction. Liquidity index (LI) was proposed by [12]to quantify liquefaction using the following relationship:

LI= (Moisture Content-Plastic Limit)/Plasticity Index

LI ≥1 is an indication for potential liquefaction

Since liquidity Indices (LI) for soils at the building site was between -0.326 to -12.653, there could not have been liquefaction of the soils.

Since the site was exposed to frequent ground vibration as the building was close to a defunct underground mineadit, heavy vehicular traffic and a railway station; with surface mining activities at a permitted distance, findings of workers in seismic areas were referred to.

[13]used the term liquefaction for the development of significant strains or strength as in fine grained soils which exhibited sand like behaviour whereas cyclic softening failure was used to describe fine grained soils with clay like behaviour. Liquidity index according to [14] who used empirical observations showed that soils were susceptible to liquefaction if they had finer fraction less than 10% and liquid limit less than 32. Soils, however, were not susceptible to liquefaction if fines weregreater than 10% and with their liquid limit greater than or equal to 32. These criteria when applied to the soils at the Tarkwa site could indicate liquefaction conditions (Table 1, Figure2). However, using plasticity index, [15] constrained liquefaction to fine grained soils with PI ≤ 12 and liquid limit, LL > 0.8. Thus thesoils at the Tarkwa site which were non-plastic could not have beensusceptible to liquefaction.

According to [13], liquidity index (LI) generally corresponds to stronger soils with lower sensibilities but cyclic loading resistance increases in fine grained soils as the potential for deformation decreases with decreasing liquidity index. They observed thatthe location of soil could cause change in soil behavior - fine grained soils could act differently, sand-like soils behave asif they were clay-like.

Soils at Tarkwa site, occurred on competent foliated quartzite intercalated with conglomerate of the TarkwaianBanket Series (Figure 1). Hence [4] linked the maximum stress direction on the rocks in the area to the minimum stress direction on the building that was at the site and interpreted cracks on the buildingto settlingunder maximum loadof the building andpossibly caused by slip during adjustment of foundation rocks toward mine openings.

5. CONCLUSION

Subsurface soils at the building site at Tarkwa are mainly dense silty sand with low plasticity, usually free draining and highly permeable.The soilscould consolidate immediately after being subjected to structural loads and have differential settling capacity. The crackson the building could have been caused by improper settling of the foundation soils before the construction of the building, making geological structures near the building the main contribution factors[4].

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