

## Effect of fines content on the compaction and CBR strength of a lateritic sub-base soil

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**ABSTRACT:** Lateritic soil deposits have served as a ready source of natural base and sub-base quality material for road construction in the tropics for a long time but in recent times are difficult to locate due to over-exploitation. Calls have been made to modify the standard quality of road construction material especially in low volume roads since the material available are either too fine or too coarse for use. However, in order to be able to make any rational modifications, the effect of fines content on the engineering properties of lateritic soils should be understood. This study seeks to investigate the effect of fines content on the compaction and CBR strength of lateritic soils of sub-base quality. Samples were recovered from a lateritic soil deposit and sent to the laboratory for testing. The material after being characterized, was reconstituted into six new samples with fines content defined as the percentage passing 0.075mm, ranging from about 11% to 43% to simulate material of varying fines content but fixed Atterberg limits. All the samples were compacted according to the Modified AASHTO compaction standard and the soaked CBR strength was also determined for each. The results are analyzed and the effect of fines content on the maximum dry density and on the soaked CBR values was discussed.

**KEYWORDS:** Lateritic soil, natural sub-base layer, fines content, compaction, CBR

### 1 INTRODUCTION

Laterites and lateritic soils are the most common naturally occurring soils in the tropics. Depending on the topographical environment in which they are formed, they tend to have physical and engineering properties that are suitable for use as road construction material and consequently they have been extensively used as base and sub base material in pavement layers. Currently, however, due to increasing traffic loadings on most highways, the use of lateritic soils as base material is being phased out for high traffic roads. However, they continue to be used as sub-base layers in high traffic pavements and as both base and subbase layers in low volume roads.

Being a non-renewable natural resource, gravel for road construction has been overexploited to the extent that there is increasing difficulty in finding suitable natural lateritic gravel material that meet the required standard specification for pavement layers in Ghana. A study in Ghana of 454 lateritic borrow pit samples (Addison 2008) showed that less than 30% pass the requirement for sub-base layer as specified in GSSRB 2006, and most of the objection has to do with the higher than required fines content. This has led to calls to make modifications to the standards to allow the use of such marginal quality materials in road construction especially for low volume roads. However, in order to be able to make any rational modifications, the effect of fines content on the engineering properties of lateritic soils should be understood.

Within the pavement, the subbase layer performs several functions. Apart from providing a uniform support for the base layer and by so doing protecting the generally weaker subgrade by reducing the stresses that reach it, it also prevents the upward migration of fines from the subgrade into the upper layers and serves as drainage material. In terms of its contribution to stability of the pavement, Huang (2009) indicated that the subbase could contribute as much as 45% of the stability of the total pavement structure against failure, thus underscoring the importance of the sub-base layer in a flexible pavement.

Theoretically, for maximum stability of base or subbase, there should be just enough fines to fill the voids among the aggregates and the entire grading curve should resemble a stable Fuller's curve as proposed by Fuller and Thompson (1907) with n-value of 0.5. For pavements in a tropical environment, Fossberg (1963) suggested that when n is less than 0.25, the fines content is excessive, but when it is more than 0.5 the aggregates tend to be stony and porous. These n

values correspond to fines content of 6.1% and 24.7% respectively for a maximum aggregate size of 20mm. For naturally occurring gravel the current local standard (GSSRB 2007) for natural gravel for G60 sub-base layer specifies among other things that the fines (percentage passing 0.075mm) should be between 15% and 22%.

In rigid pavements, Yoder and Witczack (1991) indicated that when the fines in the sub-base exceed the maximum limit by more than about 3%, pumping may initiate. There have been a number of studies of the effect of fines on the dry density and strength of blended subbase and base materials. Farooq et al. (2025) investigated the effect of fines in aggregates conforming to AASHTO gradations for a sub-base. Siswosoebrotho et al (2005), investigated the effect of fines content and plasticity on strength of base material. Wang et al (2023) used low field nuclear magnetic resonance technology (MNR) to quantify the distribution of pore space to provide an explanation of the observed effect of fines content.

These previous studies were conducted on blended aggregates of relatively low PI fines. This study seeks to investigate the effect of fines content of relatively high PI on the compaction and CBR strength of a naturally occurring lateritic soil. In this study the plasticity is held constant while the fines content is increased. Samples of a lateritic soil was reconstituted to provide fines content ranging from about 10% to 45%. The compaction characteristics of these reconstituted samples together with the soaked and unsoaked CBR were obtained and the results are discussed in terms of the effect of fines.

### 2 METHODOLOGY

Samples of a lateritic soil were obtained from a borrow pit. The samples were airdried and packed into sacks and stored in the laboratory for further testing. Part of the sample was sieved through the 0.425mm sieve and used for the Atterberg Limit tests in accordance with BS1377 Part 2-1990 to determine the liquid limit and the Plasticity Index of the natural sample.

The research design is to obtain samples with different fines content but the same Plasticity Index. To achieve this, the natural sample, designated AA-YN was first sieved through the 19mm sieve to obtain the dry sieved grading curve to be used for blending. Next, AA-YN was sieved through a nest of three sieves made up of 19mm, 4.75mm and 1mm sieves to create three portions designated 19mm-4.75mm; 4.75mm-1mm; and <1mm. These three proportions were blended by pre-selected

percentages by weight to obtain six reconstituted samples with different fines contents. Adequate quantities of these reconstituted samples were prepared and stored in plastic bags and appropriately labelled to be used for the testing programme.

A portion of each stored sample was taken and the actual particle size distribution was determined by wet sieving in accordance with BS 1377-2-1990 clause 9.3.1 and BS 1377 2-1990 clause 9.5. A second portion was subjected to the Modified Proctor compaction test in accordance with ASTM D1577 (or BS 1377 Part 4 Clause 7.3.3) to obtain the compaction characteristics. The third portion of each reconstituted sample was prepared at the OMC obtained and subjected to the unsoaked and soaked CBR test in accordance with ASTM D 1833-02 and BS 1377-4-1990 clause 7.3.3.

### 3 RESULTS AND DISCUSSIONS

#### 3.1 Sample Characterization

The natural soil was a reddish-brown lateritic soil sourced from a borrow pit being used for rehabilitation of roads in Kumasi in the Ashanti Region of Ghana. The soil has a liquid limit (LL) of 38 and a Plasticity Index (PI) of 17. The grading curve of the natural soil after being sieved through 19mm sieve is designated AA-Y-N, and is shown in Figure 1. The key grading and Atterberg limits of AA-Y-N are summarized in Table 1. It classifies as AASHTO Class A-2-6 (AASHTO, 2012) and GC in the Unified Soil Classification System (ASTM D2487).

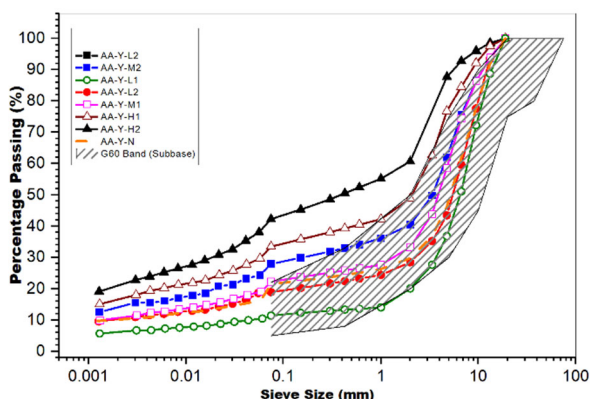


Figure 1 Grading characteristics of natural and reconstituted samples

Table 1. Table 1 Summary of Index Properties of natural soil

	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	FC (%)	G <sub>s</sub>	LL (%)	PI
AA-Y-N	76	10.7	5.1	8.2	17.3	2.69	38	16.9

The grading characteristics of the reconstituted samples are superimposed on the grading bands for a G60 natural sub-base material that is specified in GSSRB (2007) in Figure 1. The curves are approximately parallel with each other. It can be observed that while AA-Y-L1, AA-Y-L2 and AA-Y-M1 fell approximately within the grading envelope the other 3 reconstituted samples fell outside the grading envelope due to the relatively high fines content. This notwithstanding the gradings especially for AA-Y-M2 and AA-Y-H1 which marginally fell outside the grading envelope are typical of natural material currently available for pavement construction.

#### 3.2 Compaction Characteristics

The compaction characteristics of all the samples are shown in Figure 2 where the dry densities are plotted against the moulding water content for each sample, both natural and reconstituted. The key compaction parameters consisting of the maximum dry density (MDD) and the optimum water content (OMC) are summarized in Table 2 together with the optimum degree of saturation (ODS) values.

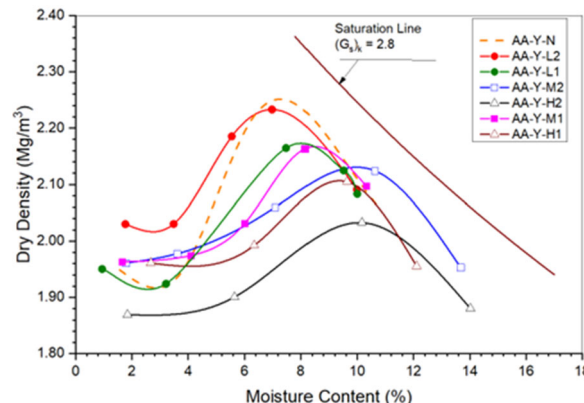


Figure 2 Dry density-moulding water content curves

Table 2. Table 2 Summary of key compaction properties

Sample ID	FC (%)	MDD (Mg/m <sup>3</sup> )	OMC (%)	ODS (%)
AA-Y-L1	11.43	2.174	8.12	79.0
AA-Y-N	16.45	2.250	7.27	83.3
AA-Y-L2	18.92	2.233	6.98	77.0
AA-Y-M1	22.24	2.193	7.26	73.1
AA-Y-M2	27.93	2.167	8.49	81.4
AA-Y-H1	33.46	2.106	9.36	79.5
AA-Y-H2	42.27	2.033	10.08	74.8

It must be noted that for lateritic soils, the G<sub>s</sub> value for the fines component is lower than for the coarse component since the oxides of iron and aluminium which have higher specific gravities are concentrated in the larger particles (Oteng Mensah, 2020). In addition, the bulk value of G<sub>s</sub> obtained in distilled water is known to underestimate the true value (Northmore et al 1992, Oteng Mensah 2020). The different reconstituted samples would therefore be expected to have different bulk G<sub>s</sub> values. However, for this investigation, an average G<sub>s</sub> value of 2.8 is assumed as an average value for computing the degree of saturation values. The saturation line thus computed is superimposed on the dry density-moulding moisture content plot in Figure 2.

The MDD and the OMC values are plotted against the FC values from Table 2 in Figure 3.

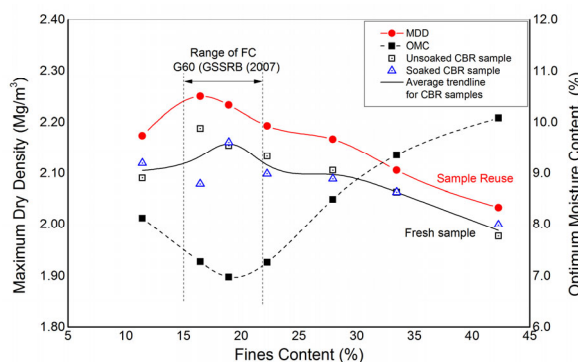


Figure 3 Variation of Dry density with Fines content

The results show that the MDD increases with fines content attaining a maximum at an optimum fines content (OFC) of about 17.5%. Beyond that the MDD decreases with increasing fines content at a rate of approximately 0.0087Mg/m<sup>3</sup> per percentage increase in fines content. Similar trend was observed in Yoder and Witzak (1975) for soils with peak MDD occurring at an OFC of about 25% and further increases resulted in an almost linear decay of MDD. A similar trend with OFC of 5% was obtained by Farooq et al. (2022) for aggregates conforming to AASHTO gradations for a sub-base when blended with non-plastic to medium-plasticity (PI less than about 7) fines. For high plasticity fines (PI > 7), on the other hand, no peak value was observed as the MDD reduces with increasing fines content.

Wang et al (2023) studying the effect of fines content on pore space distribution using low field nuclear magnetic resonance technology (MNR) observed that as fines content increases the number of micropores increases while the macropore sizes became larger attaining a maximum at a fines content of 30%. This corresponds to a honeycomb structure formed by a skeleton of coarse particles. With increasing fines content, the macropore sizes begin to shrink with continued increase in the number of small pores and the large pore structure gradually transitions to a cohesive structure. This suggests that the initial increase in fines from the 11.4% goes to fill the voids between the larger aggregates reaching a minimum void space at 17.5% fines content. After that any further increase in fines replace the coarse aggregates with fines of lower G<sub>s</sub> value and hence the MDD continues to reduce.

### 3.3 CBR Test Results

#### 3.3.1 Sample Uniformity

Table 3 and Table 4 show the details of the test results for the unsoaked and soaked CBR test respectively. The details of the sample condition for the tests are given. It can be observed that there were some deviations of the moulding water contents from the intended OMC values that are recorded in Table 2. These deviations are quantified by w-OMC values in Tables 3 and 4 for the samples for the unsoaked and for the soaked CBR tests respectively. It can be seen that most of the deviations were negative implying some drying during sample preparation. The largest deviations of -1.580% and -1.920% for the sample for the unsoaked and soaked CBR test, was obtained for sample AA-Y-L1. This relatively large drying arose from the difficulty of retaining water during compaction when the fines contents are very low. Apart from this sample, the other moulding water contents were within ±1% of the OMC. This notwithstanding, since the effect of water content changes on the dry density and CBR can be different on different samples, the measured dry densities and the CBR are corrected for the water content, deviations.

Table 3. Table 3 Summary of results of unsoaked CBR test

Sample ID	w-OMC (%)	Dry Density Mg/m <sup>3</sup>	Cor Dry Density Mg/m <sup>3</sup>	Meas CBR	Cor CBR
AA-Y-L1	-2.350	1.977	2.091	74	136
AA-Y-N	-0.138	2.183	2.188	39	44
AA-Y-L2	-0.350	2.140	2.155	56	68
AA-Y-M1	+0.293	2.126	2.134	32	48
AA-Y-M2	-0.590	2.086	2.106	20	32
AA-Y-H1	-0.177	2.058	2.063	8	10
AA-Y-H2	-0.440	1.964	1.977	28	31

Table 4. Summary of results of soaked CBR test

Sample ID	w-OMC (%)	Dry Density Mg/m <sup>3</sup>	Cor Dry Density Mg/m <sup>3</sup>	Meas CBR	Corr CBR
AA-Y-L1	-2.260	2.028	2.120	67	50
AA-Y-N	-0.858	2.022	2.079	29	24
AA-Y-L2	-0.750	2.129	2.161	40	35
AA-Y-M1	-0.187	2.091	2.099	33	32
AA-Y-M2	-0.390	2.075	2.089	17	14
AA-Y-H1	+0.363	2.054	2.063	13	23
AA-Y-H2	-0.760	1.979	1.999	20	13

#### 3.3.2 Correction for Dry Densities

In order to correct the dry densities for the w-OMC deviations, the procedure proposed by Horpibulsuk et al (2008) was adopted. The constants A<sub>d</sub> and A<sub>w</sub> were determined from equations (1) for each sample.

$$A_d = \frac{OMC}{ODS^{B_d}} \tag{1}$$

$$A_w = \frac{OMC}{ODS^{B_w}} \tag{2}$$

In these equations the values of B<sub>d</sub> = 0.72 and B<sub>w</sub> = 2.16 proposed by Horpibulsuk et al 2008 for silty clay were adopted. The corrected degree of saturation (S)<sub>cor</sub> was computed from equation (3), where S is the degree of saturation computed from the measured water content (w) and the measured dry density (rd) using G<sub>s</sub> = 2.8, but expressed in decimals. In the computations of (S)<sub>cor</sub> in equation (3), A<sub>d</sub> is used when w-OMC < 0 and A<sub>w</sub> is used when w-OMC > 0.

$$(S)_{cor} = \left( S^{B_d} - \frac{w-OMC}{A_d} \right)^{1/B_d} \tag{3}$$

$$\rho_d = \frac{G_s}{\left( \frac{wG_s}{S_r} + 1 \right)} \tag{4}$$

The corrected dry density is then computed from the (S)<sub>cor</sub> and the OMC with G<sub>s</sub> = 2.8 using equation (4). All the corrected dry densities were only slightly higher than the measured values except for AA-Y-L1 which were about 0.1 Mg/m<sup>3</sup> higher. The corrected values have been plotted in Figure 3. It is clear that when the lateritic samples are compacted at the OMC with the same compactive effort but using fresh samples each time, they give dry densities that are lower than the MDD values obtained by sample reuse. This observation is a well-known characteristic of many lateritic soils and has been discussed in Ampadu and Arthur 2022, Gidigasu 1970, Furukawa and Fujita 1990 and Hammond 1970. It is further observed that for this lateritic soil, this trend is consistent for all fines contents considered and the ratio of the dry density to the respective MDD is consistently about 0.95. This means that compaction by sample reuse (incremental moulding water content) gives MDD values that are 5% higher than when compacted by fresh samples (and one step increase in water content to OMC).

#### 3.3.3 Correction for CBR Values

It must be noted that the intention was to determine the CBR at the respective OMCs and at the (ρ<sub>d</sub>)<sub>cor</sub>-values. However, the measured CBR values in Table 3 and Table 4 have been influenced by the w-OMC and the difference between the dry density (ρ<sub>d</sub>) and the (ρ<sub>d</sub>)<sub>cor</sub> values. Since CBR values are known

to be sensitive to both the dry density and the moulding water content (Tatsuoka et al 2015), in order to obtain the trend of the effect of fines contents the effects of  $w-OMC$  and  $(\Delta\rho_d)_{cor-\rho_d}$ , must be accounted for. For this correction, it is noted in Ampadu et al 2025, that for a lateritic subgrade soil at dry density exceeding  $1.73\text{Mg/m}^3$ , the CBR increases by 11 and reduces by 25 for every 1% reduction and increase respectively in  $w-OMC$ . Also, equations (7) and (8) are inferred approximately from Ampadu et al 2025 for the effect of dry density on unsoaked and soaked CBR respectively.

$\Delta CBR = 11(w - OMC)$	when $(w-OMC) < 0$	(5)
$\Delta CBR = 25(w - OMC)$	when $(w-OMC) > 0$	(6)
$CBR_{un} = 0.784\rho_d^{7.8}$		(7)
$CBR_s = 1.103\rho_d^{4.8}$		(8)

These observations were applied to the  $(w-OMC)$  and  $(\rho_d)_{cor-\rho_d}$  values in Tables 3 and 4, to obtain the corrected CBR values. The corrections varied between an increase of between 2 and 42 in the unsoaked CBR and an increase of 10 and a decrease by 14 in the soaked CBR values. The corrected unsoaked and soaked CBR values have been plotted against the fines content in Figure 5 and Figure 6 respectively.

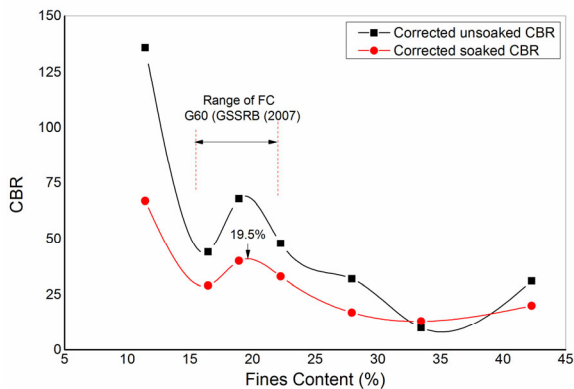


Figure 4 Variation of fines content with Soaked and Unsoaked CBR

The results appear to oscillate but there is a clear trend of reduction in unsoaked and soaked CBR with increasing fines. There appears to be an OFC of the order of 20% for both the unsoaked and soaked CBR. This observation is similar in trend to the results of Siswosoebrotho et al (2005), investigating the effect of fines content and plasticity on strength of base material, observed an OFC of 5% for CBR trend, similar to that of the MDD. However, the results of an OFC, is contrary to that of Farooq et al. (2022) whose results for soaked CBR, unlike the MDD, showed a monotonic reduction in CBR with increasing fines for all plasticity fines. The range of fines content of 15 to 22 % specified in G60 in GSSRB coincides with the oscillation. Also the trend suggests that at very high fines content beyond about 30% the soaked and unsoaked CBR coincides and beyond that the CBR appears to increase with increasing fines content. This may be due to increasing excess pore water pressure with increasing fines content as suggested by Black et al (1965)

#### 4 CONCLUSION

A lateritic soil of liquid limit of 38 and PI of 19, which is locally typical of natural gravel available for subbase

construction, was reconstituted into six additional samples with fines content ranging from as low as 11% to as high as 42%. The following key conclusions were obtained when they were subjected to compaction and soaked and unsoaked CBR testing:

- At the same compactive effort, the dry densities of lateritic samples compacted at OMC using fresh samples give only 95% of the MDD values obtained by sample reuse for the range of fines content.
- The OFC for the maximum MDD is about 17.5% and thereafter decays at a rate of approximately  $0.0087\text{Mg/m}^3$  per percentage increase in fines content.
- The peak CBR values coincides with an OFC of the order of 20% for both unsoaked and soaked CBR

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