INFLUENCE OF GEOLOGY AND PHYSICAL PROPERTIES ON STRENGTH CHARACTERISTICS OF LATERITIC GRAVELS FOR ROAD PAVEMENTS

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Lateritic gravels are the commonly available local material for road and airfield construction in the tropics and subtropics. Because of the wide variations in their nature and physical properties, the selection of an appropriate type of lateritic gravel presents some problems. In the present study the effect of geology, climate, and topography on the nature and formation of such gravels is studied. As a result of the investigations, the lateritic gravels are divided into 4 groups on the basis of geology and physical properties. The study indicates that the proposed groups have a distinct range of engineering properties that can be depicted from simple physical properties. The results obtained have been applied to road failure studies in Ghana, and some interesting observations on the performance of each group of samples are made. The study is considered useful for making a judicious choice of lateritic gravels for satisfactory performance and adequate stability of road pavements.

• LATERITIC gravels are the traditional road-building materials in many tropical countries, especially in Asia and Africa. The value of lateritic gravels as a material of construction has been studied in a good deal of detail by a large number of investigators in many parts of the world. On account of the physical vastness of the areas over which laterites are formed and the wide variations in climatic conditions and geological formations, it has not been possible to generalize the physical properties and engineering behavior of lateritic soils. In addition, no satisfactory classification system has so far been developed that is likely to divide laterites and lateritic soils into different groups, which would reflect the engineering properties and field behavior of such soils. A large number of researchers agree that, for studying the formation and physical properties of lateritic soils and gravels in a generalized way, the pedological grouping is of a considerable value, for it takes into consideration climate, geology, relief, and vegetation.

In Ghana, Gidigasu (14) has studied fine-grained lateritic soils over various geological formations in the 4 climatic zones of the country, namely, coastal savannah, forest, rain forest, and interior savannah. The 4 climatic zones have a distinct range of rainfall as shown in Figure 1, and the samples from each region show certain trends of physicochemical and index properties. For engineering use, such generalizations do provide guidelines on the mode of formation and physical properties of the soils, but for laterite gravels this is of a limited value in terms of assessing their engineering behavior.

On any road or airfield project, thousands of samples must be tested for the selection of appropriate materials for design and construction. A number of highway authorities have adopted physical tests such as particle-size distribution and Atterberg limits

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for the preliminary selection of soil and gravel for road bases and subbases. The materials satisfying the grading and Atterberg limits must also be tested for strength before they are accepted for construction. On account of the very large variation of physical and engineering properties of lateritic gravels, it is considered desirable to have some system for their grouping based either on genetics or on simple physical tests that would reflect broadly the engineering characteristics of the materials. Such a grouping can assist in a better understanding of the behavior of laterites and in reducing the amount of detailed testing on a project. On the basis of such a grouping, only those materials likely to show strength characteristics within specified limits of base, subbase, and fill material are tested in much detail. de Graft-Johnson et al. (9) divided the lateritic gravels into 4 groups and studied the physical and engineering properties of each group. The study indicated that such a grouping, based mainly on the physical characteristics of gravels, could assist very effectively in providing useful guidelines on the strength characteristics. The present study is an extension of the earlier investigation and involves 490 samples of lateritic gravels from the various regions of Ghana. Any samples having more than 50 percent passing the No. 8 ASTM sieve were not included.

The groups established in the present study should not be confused with soil classification systems such as the Unified Soil Classification or classification systems of the U. S. Bureau of Public Roads or the American Association of State Highway Officials. According to the classification systems, most of the lateritic gravels fall broadly in 2 groups, and even these 2 groups cannot effectively be used for preliminary selection of materials for pavement structures. For example, in the Unified Soil Classification System, all lateritic gravels fall in the silty gravel and gravel-sand mixtures or the clay gravel and gravel-sand-clay mixtures. Similarly in the AASHO or BPR classifications, most of the gravels fall in groups A-1 and A-2.

OBJECTIVES OF STUDY

The objectives of the present study were the following:

1. To study the influence of geology, climate, and topography on the properties of laterite gravel;
2. To evolve a grouping system for lateritic gravels by using routine physical tests;
3. To establish whether the groupings evolved can assist in depicting the range of engineering properties for each group and thus facilitate the preliminary selection of materials on a project; and
4. To determine whether the proposed groupings have any bearing on the field behavior of lateritic gravels in road pavements.

FACTORS INFLUENCING PHYSICAL NATURE AND FORMATION OF LATERITES

The various factors influencing the formation of soils are parent materials (geological formation and age), climatic conditions, vegetation, and topography.

Geology

Figure 1 shows that in general Ghana is divided geologically into 4 groups:

1. Acid igneous, which includes rocks like granites, acid gneiss (Dahomeyan series) and quartzites (Togo and Tarkwaian series);
2. Basic igneous, which includes rocks like basalt, gabbro, dolerite (Dahomeyan series), and intrusives;
3. Metamorphic rocks such as shales, phyllites, and schists (Sekondian, Accraian, Voltaian, and Birrimian series);
4. Sedimentary rocks, such as sandstone and limestone (Cretaceous, Amisian, Accraian, Voltaian, and Buem series).

The study of typical soil profiles over various geological formations in Ghana revealed that the materials formed over granite and gneiss were generally coarse in texture, and the kaolin clay mineral in such soils was formed because of the weathering of quartz, feldspar, and mica. The quartz and mica were very much resistant to weathering and remained unchanged except for leaching of iron from biotite. The materials formed on these rocks were generally sandy and silty in nature with a mottled zone near the surface and iron pan layers 1 to 3 ft thick between 3 and 10 ft from the surface.

Gravels on basic igneous rocks, such as basalt, gabbro, and dolerite, had a high concentration of calcium-rich feldspar and other minerals, which were likely to weather quickly to form amorphous hydrous oxide. The absence of quartz tended to produce plastic materials with fine gradings. Such soils had low permeability and high concentration of iron content, which was not readily removed by leaching.

The gravels on shales, phyllites, and schists, formed initially from clay and silt deposits including some secondary minerals such as mica and quartz from the micaceous quartz veins, were generally clayey in nature and had a reasonable concentration of iron oxide. Laterite hardpans generally developed over such formations near the crest of the slopes. The detrital hardpans mixed with residual soil were good gravels. The residual soils on lower slopes of such formations were poorly drained micaceous clays with varying proportions of quartz obtained as detrital material from quartz veins.

Gravels overlying sandstone and quartzites had a large proportion of quartz in their fine fractions in the form of cemented sand grains (sandstone) or secondary quartz (quartzite). The cementing materials in such rocks were iron and calcium salts that were leached out in the profiles, leaving behind quartz that was unaffected by weathering. The residual materials were generally well-drained sandy gravels. The iron hardpans in such profiles were often developed over high grounds. The effect of parent rock on the particle-size distribution of residual soils is shown in Figure 2.

Climate

The climatic factors influencing the formation of various soils are temperature and rainfall. For example, the coastal and interior savannah zones of Ghana are areas where there is intermediate rainfall and where total evaporation in a year exceeds rainfall; this initiates an upward capillary movement of the product of chemical weathering. The forest zone has a high rainfall, and the soils are covered with thick vegetation. This tends to produce deep chemical weathering and produces quick induration when the soils are exposed. The water table in this region is generally high, and erosion is low.

D'Hoore (11) in his pedologic map of Africa divided the lateritic soils into ferruginous, ferralitic, and ferrisol soils and showed a generalized distribution of those soils depending on climatic conditions alone. According to D'Hoore, the ferruginous soils generally occur in areas with 20 to 60 in. of rainfall per year. The ferralitic and ferrisol soils were formed in areas with rainfall of more than 60 in. per year. Lyon Associates (19) noted that most of the samples tested by them showed a good correlation between the index properties and the pedologic classification proposed by D'Hoore. The test results indicated that ferruginous soils had liquid and plastic limits of less than 50 and 25 respectively, whereas ferralitic and ferrisol soils had liquid and plastic limits of more than 50 and 20 respectively. These factors do form a basis for classifying fine-grained materials in a very generalized way, though this classification is not entirely satisfactory in the case of gravelly materials where a large number of additional variables affect the grain-size distribution and make the assessment of engineering characteristics very complex. The use of such classification systems was, therefore, considered of a limited value in the present study.

Topography

It had generally been noted that most of the borrow areas of good base and subbase gravel were located either on high grounds as primary residual laterite that was rich in sesquioxides of iron and aluminum or on midslopes as secondary laterite that had sesquioxides of iron and aluminum transported into the profile and deposited by groundwater movements. It was, therefore, inferred that laterites formed over high slopes

Figure 1. Geologic map of Ghana and sites of laterite gravel samples.

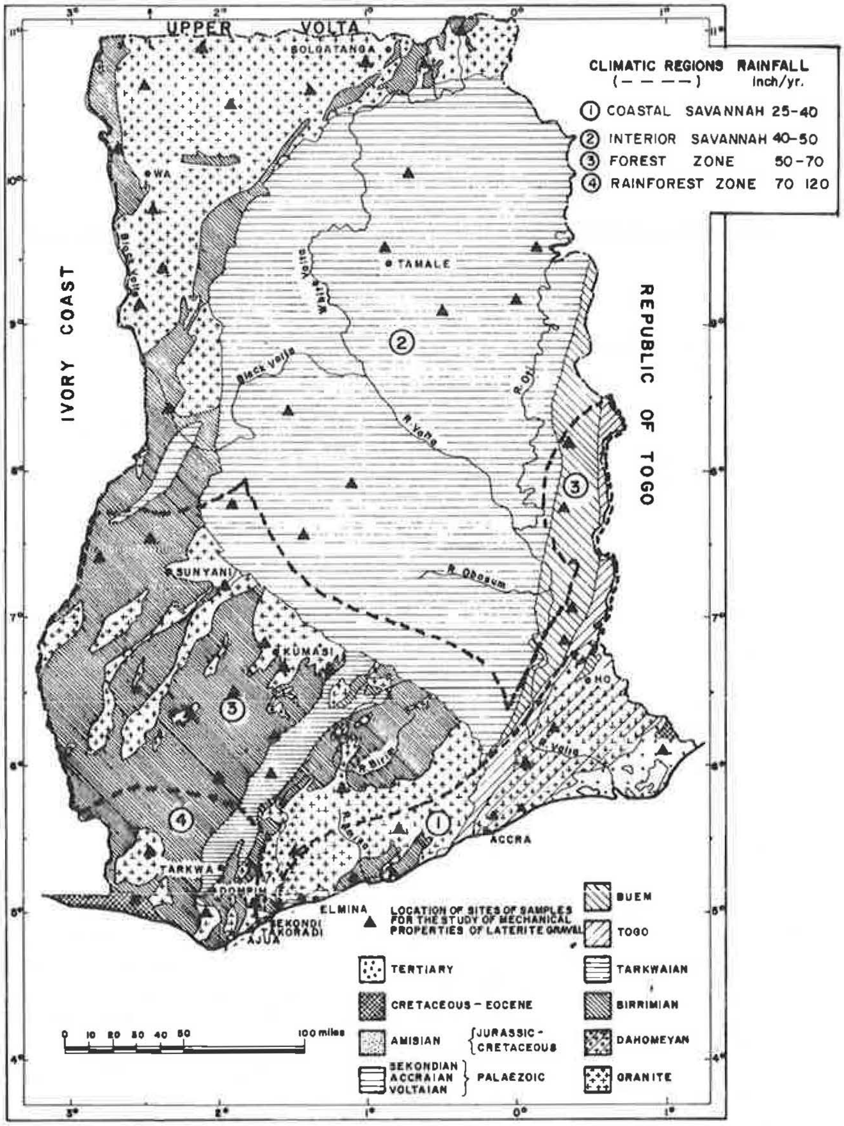
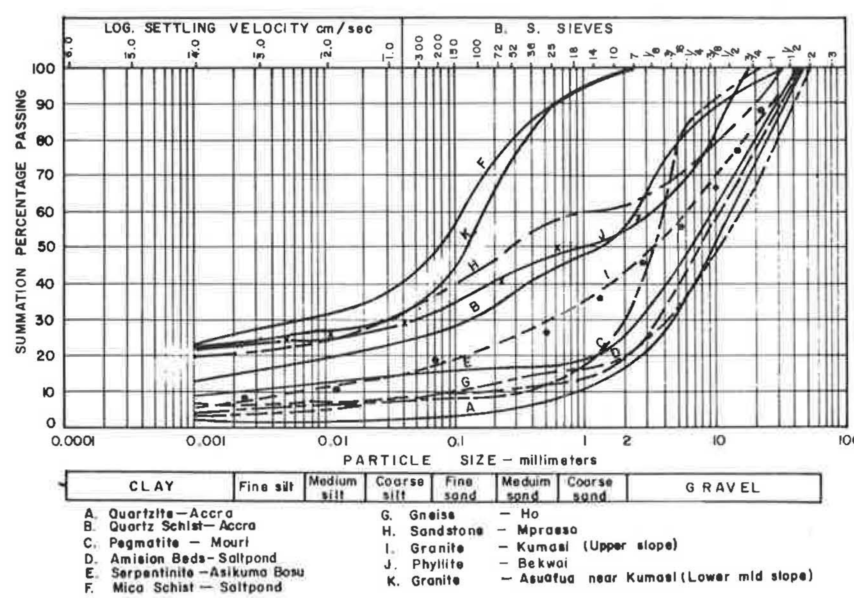


Figure 2. Grading curves of lateritic soil on various parent rocks.



have relatively fewer fines and, therefore, are more suitable for road pavements than gravels found on lower slopes and in valleys.

In the present study, only 14 out of 490 samples were obtained from borrow areas on the lower slopes or in the valleys. All of the other samples were from the upper and middle slopes or from areas where the topography was plain. The samples collected from low slopes and valleys were very plastic and were an unpredictable mixture of clay and gravel.

SELECTION OF SAMPLES AND TESTING

The 490 samples were subjected to the following tests: particle-size distribution, Atterberg limits, moisture-density relations using Ghana compaction standard (compaction in a standard CBR mold in 5 layers with a 10-lb AASHO hammer from an 18-in. drop), and CBR (soaked and unsoaked). Triaxial tests were also conducted on few selected samples. These samples included the soils tested at the Building and Road Research Institute and by the Materials Branch of the Public Works Department of Ghana in connection with a number of road projects in the country. The inclusion of samples from the Materials Branch not only provided a broad basis for this study but also helped to assess the practical value and utility of the findings of this investigation. The distribution of various samples selected in the present study is shown in Figure 1.

Of the 490 samples selected for this study, 38 percent came from climatic regions having rainfall between 40 and 60 in. and 62 percent from regions having rainfall between 60 and 120 in. per year.

MECHANICAL STRENGTH OF COARSE GRAVEL

Several investigators, Ackroyd (2), Clare (8), de Graft-Johnson et al. (9), and Novais-Ferreira and Correia (17), have suggested the importance of mechanical strength of aggregates in relation to their mechanical breakdown and weathering under different environments in the field. A weak gravel is likely to break down because of chemical weathering or mechanical processes during and after construction. The breakdown of gravels in base and subbase layers tends to change the gradings and Atterberg limits of the material and to cause a considerable distress in road pavements. It is, therefore, important that a minimum value of mechanical strength for the coarse fractions be specified in addition to the specified values of Atterberg limits, particle-size distribution, and CBR test. These are the tests generally included in most of the standard specifications for road gravels. de Graft-Johnson et al. (9) have suggested that the aggregate impact test is a useful criterion for assessing the mechanical strength of laterite gravels, and this can form a reasonable basis for inclusion in future specifications. [In the aggregate impact test, BS-812, resistance to impact is measured on a 1½-in. deep bed of ½-in. chippings in a 4-in. diameter mold struck 15 blows by a 30-lb hammer falling from a height of 15 in. The percentage of fines passing No. 7 BSS (2 mm) as a result of the impact is known as aggregate impact value.] As a result of a recent study on the mechanical strength of lateritic gravels of Ghana (4), the following is recommended for rating gravels of different mechanical strength:

Aggregate Impact Value (percent)	Los Angeles Abrasion Value (percent)	Performance Rating
30	40	Excellent
31 to 40	41 to 50	Good
41 to 50	51 to 60	Average, generally unsuitable
>50	>60	Very poor

The study further suggests that any gravels having aggregate impact values of more than 40 percent and Los Angeles abrasion values of more than 50 percent should be avoided for base construction.

PHYSICAL PROPERTIES

Particle-Size Distribution

Besides the mechanical strength of a gravel, the most important factor influencing its value as a material of construction is grading. The particle-size distribution of the samples was examined to determine the limits within which the distribution varies in lateritic gravels. Although the total variations of different fractions in the samples studied were wide, there was some similarity in the grain-size distribution of samples obtained from the areas having similar climate and geology. Geologic and climatic factors did influence the gradings of the samples within reasonable limits, though these factors could not exclusively be used as a basis for grouping because the variations in about 13 percent of the samples from the same geologic and climatic region followed no distinct pattern of grading. This was attributed to the predominance of other factors over geology and climate in the formation of such soils.

Earlier de Graft-Johnson et al. (9) suggested 4 grading envelopes within which most of the lateritic gravels could be accommodated with ease. These grading limits for each group have been slightly modified as a result of further studies of a number of samples from the road pavements and also of considerations of the influence of geology on such gravels. The slightly modified grading envelopes as a result of the present study are shown in Figure 3.

In groups 1 and 2, 80 and 83 percent of the samples studied were formed over granite and gneiss, whereas 20 and 17 percent of the samples belonged to other geological formations. In groups 3 and 4, 83 and 92 percent of the samples were formed over phyllite, schist, shales, and limestone, whereas only 17 and 8 percent belonged to granite and gneiss. This tends to suggest a strong influence of geology on the particle-size distribution of the lateritic gravels. No definite conclusion could be drawn, however, on the effect of rainfall on the particle-size distribution of the gravels collected from different regions of Ghana.

To see the significance of the proposed grouping, we used a statistical method known as multiple measurements (12) to discriminate between 2 groups. The general problem was set up as a function of the form

$$Z = Y_1X_1 + Y_2X_2 + Y_3X_3 + \dots + Y_nX_n$$

where X_1, X_2, X_3, and X_n are variables that in the present study are liquid limit, plasticity index, maximum density, optimum moisture content, and California bearing ratio; and Y_1, Y_2, Y_3, and Y_n are the corresponding weights or coefficients to give the discriminating power. If the 2 groups to be discriminated were 1 and 2 and there were n_1 sets of measurements for group 1 and n_2 sets of measurements for group 2, the ratio of the differences between group means Z_1 and Z_2 to the differences between the groups as represented by standard deviation was maximized as

$$G = (\overline{Z}_1 - \overline{Z}_2)^2 \Bigg/ \left[\sum_{i=1}^{n_1} (Z_i - Z_1)^2 \sum_{j=1}^{n_2} (Z_j - Z_2) \right]$$

By differentiation with respect to the individual coefficients, we calculated the differences among and within the groups and the mean square for each difference. The ratio of the mean square among groups to the mean square within the group, known as the F-ratio, was calculated. The comparison of the experimental F-ratio to the statistical F-ratio indicated that the 4 groups proposed were very highly significant in terms of their properties such as liquid limit, plasticity index, maximum density, optimum moisture content, and CBR values. The results of the discriminatory analysis for the 4 groups are given in Table 1.

Atterberg Limits

The Atterberg limits tests carried out on air-dried samples by using a standard procedure did not indicate a separate range of Atterberg limits for the proposed 4

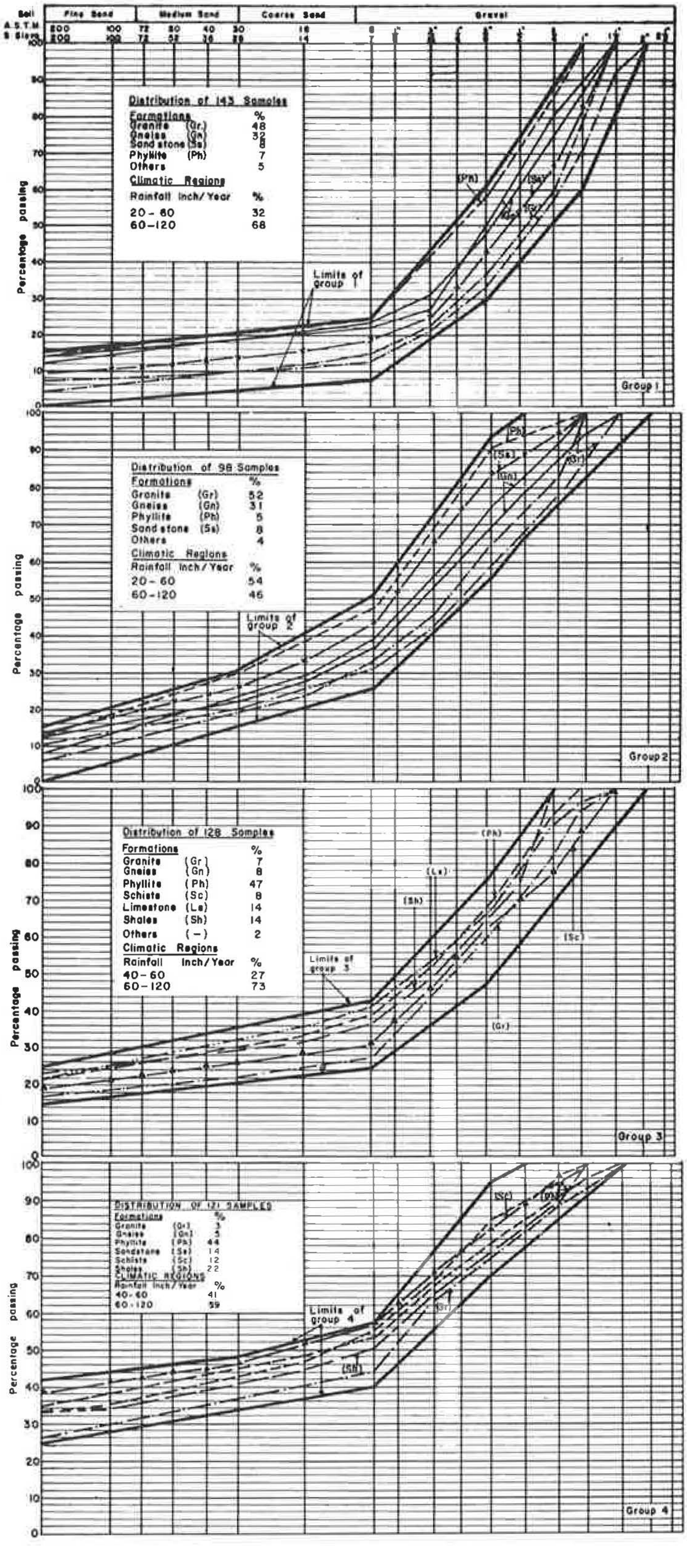


Figure 3. Typical grading curves of 4 sample groups on different geologic formations.

grading envelopes. There was considerable variation of these limits for samples falling in each grading envelope, though as a general rule the Atterberg limits increased progressively from group 1 to group 4. In view of a certain amount of overlapping in the Atterberg limits, no separate range of values could be given for each group. The histograms indicating the distribution of these values are shown in Figure 4. In addition, these values were plotted on Casagrande's plasticity chart as shown in Figure 5. Such variations of Atterberg limits were considered normal, for these limits depended on a large number of factors such as geology, relief, state of dehydration of iron, nature of clay minerals, and residual or nonresidual soil. The general variations of liquid limit, plastic limit, and plasticity index for all 4 groups are given in Table 2.

Moisture-Density Relations

The engineer is mainly interested in the suitability of a compacted soil when it is used as a material of construction. The assessment of suitability in the present study was made through the strength characteristics of compacted gravels under different conditions of moisture contents. The 3 modes of compaction generally adopted in Ghana are as follows:

Compaction Standard	Energy ($ft\text{-}lb/ft^3$)
Modified AASHO	56,750
Ghana	22,500
Proctor's	12,375

Ghana compaction is between the modified AASHO and the Proctor's compaction in terms of compactive energy. Ghana compaction standard is generally adopted on most of the road projects in Ghana; therefore, this standard was used for arriving at the moisture-density relations for most of the soils included in this study. Hammond (16) conducted a separate investigation on a few typical samples from each of the 4 groups to determine the effect of 3 levels of compaction on the strength characteristics of the soil; those results are reported elsewhere.

The moisture-density relations of some typical samples of gravels falling in the 4 grading envelopes are shown in Figure 6. The maximum densities and optimum moisture contents and their median values are shown in Figure 7. The maximum, minimum, and mean values in addition to standard deviation values are also given in Table 2. The range of optimum densities and optimum moisture contents for the Ghana compaction standard was relatively little different between sample groups 1 and 2, but this difference increased progressively in sample groups 3 and 4. Each group of gravels showed maximum densities in a rather narrow range, though the values overlap to some degree, and this was considered normal. The very fact that samples belonging to different groups showed their maximum optimum densities and optimum moisture contents in different ranges indicated that there was a strong influence of grading on the moisture-density relations of a gravel.

An attempt was, therefore, made to correlate grading with the maximum density. This was achieved by converting the grading into a single parameter known as the fineness index. This index is a modified form of the fineness modulus used in concrete aggregates and of the granulometric modulus used by Novais-Ferreira and Correia (17) for gravel studies. The set of sieves used in Ghana for particle-size distribution is slightly different from the set used by the researchers referred to above; therefore, the parameter in this study was called the fineness index (FI) to avoid confusion. The fineness index in the present study was the accumulative value of the percentage passing the ¾-in., $^3/_{16}$-in., No. 8, No. 30, and No. 300 ASTM or No. 7, No. 25, and No. 200 BS sieves divided by 6. The increasing values of FI reflected the finer nature of the materials.

An attempt was made to develop correlations between FI and maximum density for all 4 groups. The plotted points and their regression curves are shown in Figure 8. There is significant linear correlation between the fineness index and the maximum density for each group of lateritic gravels.

Table 1. Results of statistical discriminant analysis.

		Mean Value									
Group	Number of Samples	Liquid Limit	Plastic Limit	Maxi-mum Density	Optimum Moisture Content	CBR	Experimental F-Value[a]			Statistical F-Values[b]	Remarks
1	143	35.56	14.96	133.95	9.06	64.22	3.7			3.130	Satisfactory
2	98	30.76	11.60	135.00	8.92	63.01		13.0			
3	128	36.71	15.41	130.48	10.02	45.55			24.4	3.112	Highly significant
4	121	42.31	19.74	129.22	11.00	30.93				3.132	Very highly significant
2	98	30.76	11.60	135.00	8.92	63.01				3.138	
3	128	36.71	15.41	130.48	10.02	45.85	9.9	24.4			Highly significant
4	121	42.31	19.74	129.22	11.00	30.93				3.170	Very highly significant
3	127	36.71	15.41	130.48	10.02	45.85					
4	121	42.31	19.74	129.22	11.00	30.93	9.1			3.130	Significant

[a]Ratio of mean square among groups to the mean square within the group; the higher the experimental F-value relative to the statistical F-value, the more significant is the difference among the groups.
[b]1 percent confidence.

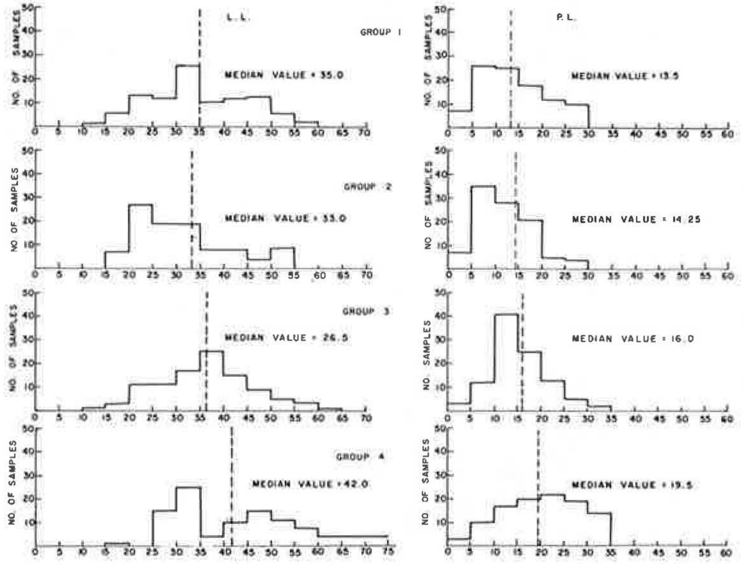


Figure 4. Distribution of liquid limit and plasticity index of 4 sample groups.

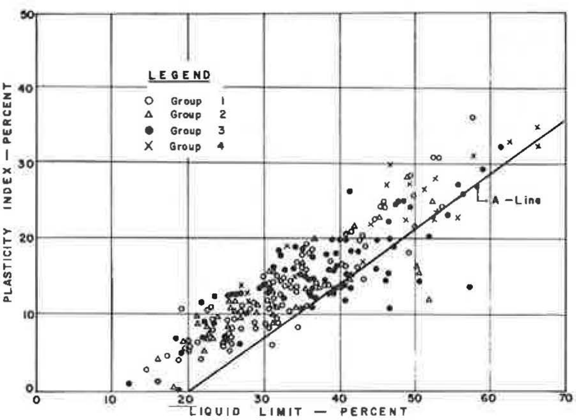


Figure 5. Casagrande's chart of limits of 4 sample groups.

Table 2. Limits, density, and moisture content of 4 sample groups.

Group	Value	Liquid Limit	Plastic Limit	Plasticity Index	Maximum Dry Density	Optimum Moisture Content
1	Maximum	58.4	31.0	36.3	141.8	13.8
	Mean	34.4	19.9	14.4	139.0	9.2
	Minimum	14.5	8.01	1.6	123.2	6.1
	Standard deviation	10.3	4.5	7.3	17.3	1.5
2	Maximum	53	40.0	28.0	142.2	13.5
	Mean	31.4	18.9	12.5	139.1	8.9
	Minimum	16.7	1.0	4.0	130.8	5.6
	Standard deviation	9.21	6.32	5.48	3.36	2.36
3	Maximum	61.8	44.4	31.3	138.5	15.8
	Mean	37.2	24.7	15.3	130.0	9.92
	Minimum	12.9	10.0	0.9	110.0	2.07
	Standard deviation	9.84	7.66	5.36	4.52	2.07
4	Maximum	73	48.0	34.9	133.9	16.4
	Mean	43.4	23.3	20.6	126.6	11.4
	Minimum	18.4	10.2	3.2	120.6	8.9
	Standard deviation	13.74	8.1	7.29	3.82	1.89

Figure 6. Moisture-density relations of 4 sample groups.

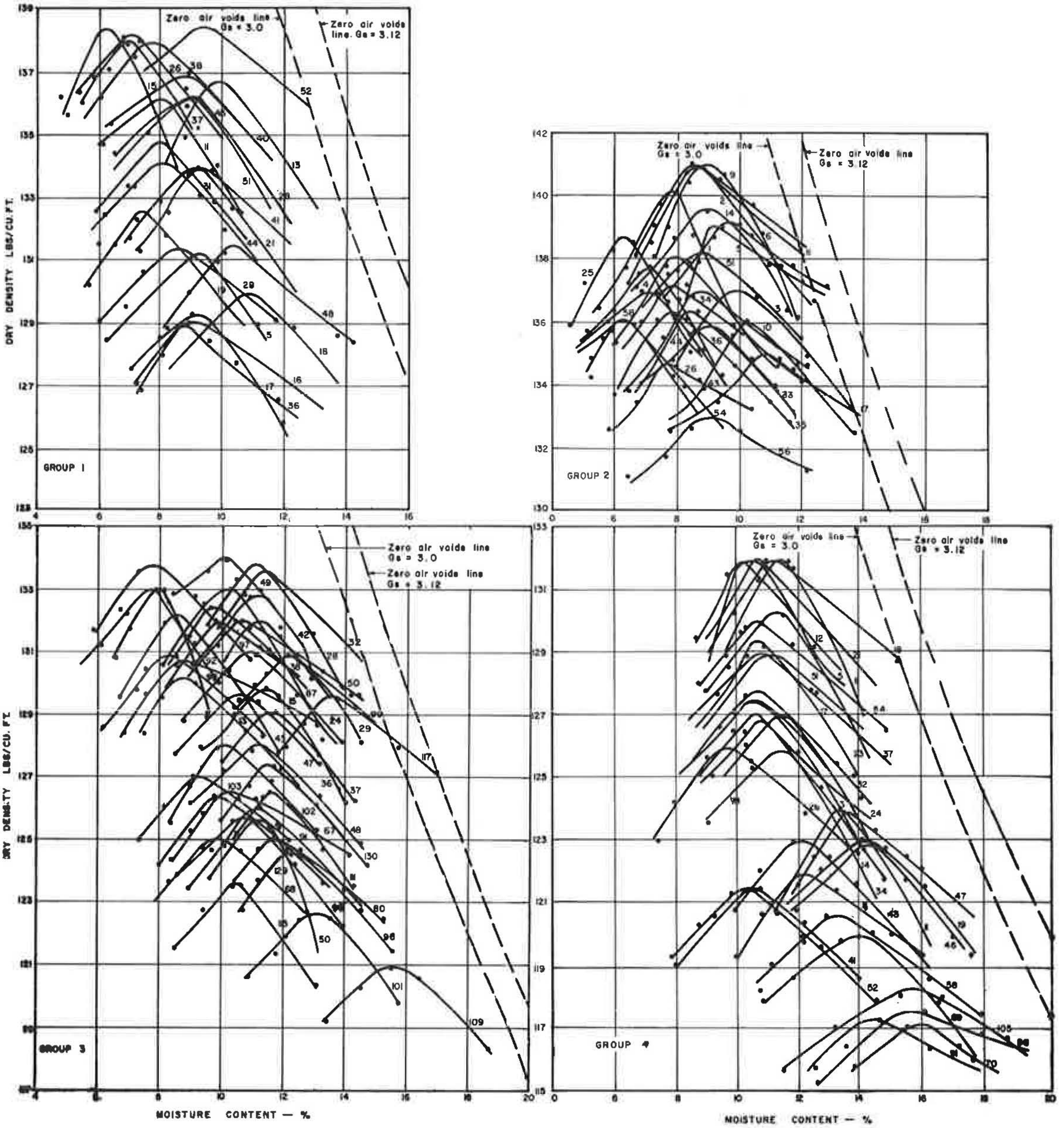


Figure 7. Distribution of maximum dry densities of 4 sample groups.

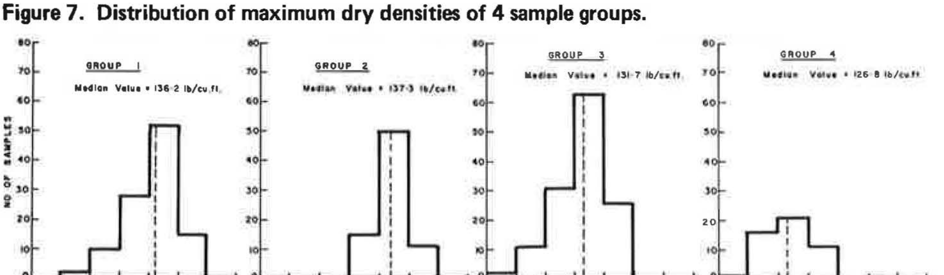
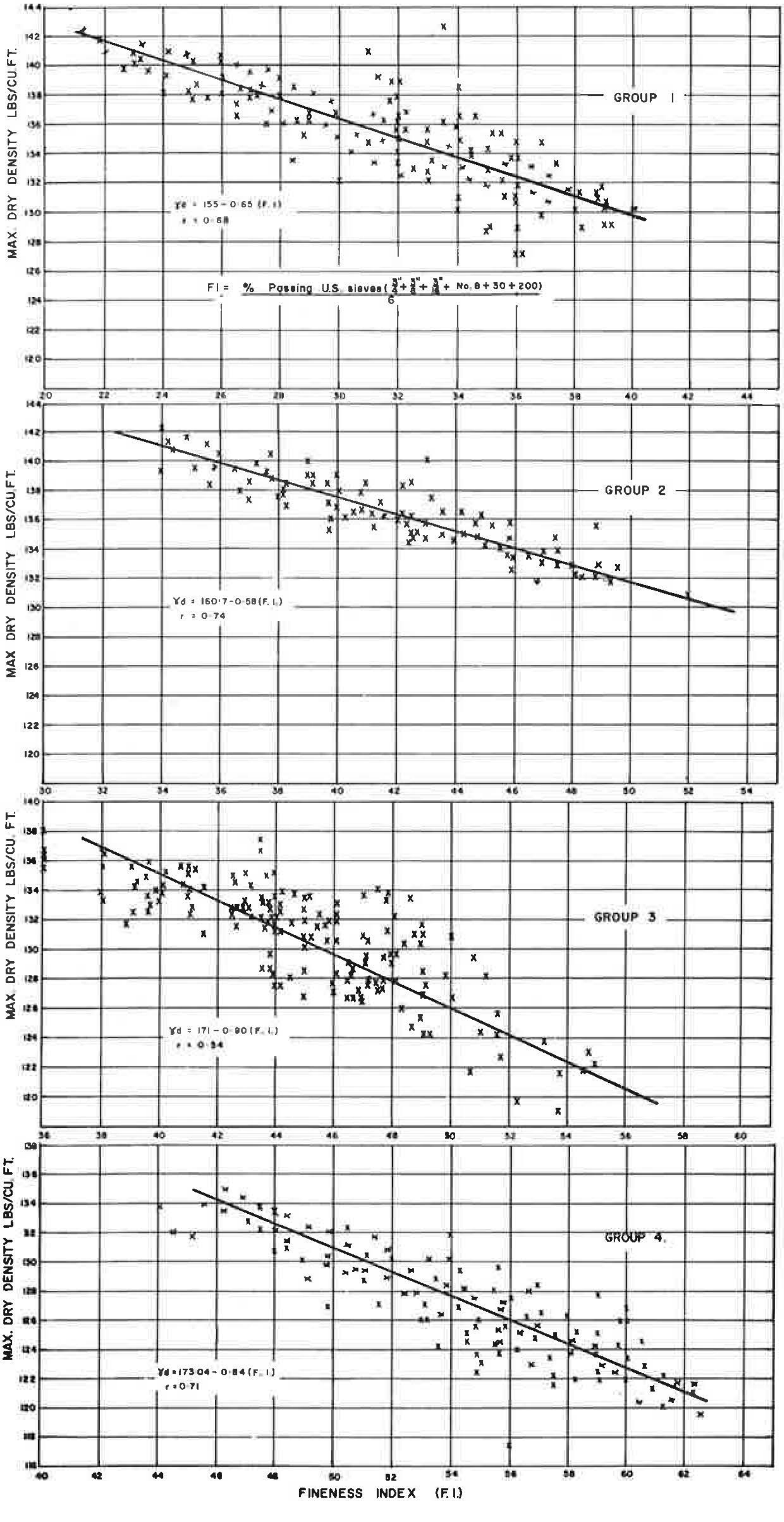


Figure 8. Relation of fineness index and maximum dry density of 4 sample groups.



STRENGTH CHARACTERISTICS

The strength characteristics of gravels in the present investigations were studied by means of the CBR tests, and shear parameters were determined for a few selected samples in a triaxial cell. The CBR test was considered an indirect test for the evaluation of strength characteristics of pavement materials. The soaked CBR values were determined for each sample at optimum moisture content by using Ghana compaction standard. The histograms showing the distribution of CBR values for the 4 sample groups are shown in Figure 9.

The 2 important factors likely to influence the strength characteristics of a gravel under worst conditions of moisture are its maximum density and plasticity characteristics of its fines. In a previous study by de Graft-Johnson et al. (9), a parameter known as the suitability index (SI) was used to assess the CBR values of lateritic gravels; the index is based on the percentage of coarse gravel fractions in a soil, the liquid limit, and the plasticity index of its fines.

$$SI = A/B \log_{10}C$$

where

A = fraction retained on No. 8 ASTM or No. 7 BS sieve,
B = liquid limit, and
C = plasticity index.

The present study indicated that the SI was a useful parameter for assessing the strength characteristics of samples collected from the same climatic and geological areas. However, the results showed a certain amount of scattering when samples from different climatic and geologic regions were plotted together (Fig. 10).

The grading and plasticity characteristics have a considerable influence on the maximum density and the strength characteristics of a material. An attempt was, therefore, made to use maximum density and plasticity index as 2 parameters for assessing the strength characteristics of a compacted gravel. The maximum density at Ghana compaction and the fineness index obtained from grading had significant correlations. It was further seen that log of (maximum density/PI) had linear correlation with soaked CBR values, and the following general expression was established:

$$CBR = C_1 \log (\gamma d\ max/PI) + C_2$$

where C_1 and C_2 are constants with different values for the 4 groups. The plotted values of (maximum density/PI) against CBR values on a semilog scale are shown for the 4 groups in Figure 11. The correlation coefficients in all the groups are very significant. Combining the 2 statistical relations between FI and maximum density and also between log (maximum density/PI) and CBR values made it possible to assess the CBR values of each sample group at a given compaction standard from simple physical tests, namely, the grading and the Atterberg limits. The statistical relation for the 4 groups of gravel are shown below.

Group	CBR	Correlation Coefficient
1	$42.6 \log [(146.4 - 0.335 \times FI)/PI] + 20.63$	0.62
2	$76.0 \log [(149 - 0.287 \times FI)/PI] - 23.89$	0.84
3	$50.0 \log [(144.4 - 0.296 \times FI)/PI] - 3.86$	0.64
4	$41.8 \log [(151.8 - 0.47 \times FI)/PI] - 4.34$	0.71

The regression lines for the actual CBR values and the statistical CBR values for all 4 groups are shown in Figure 12, and they show significant correlations.

Triaxial Testing

An attempt was made to study the shear parameters of a few typical gravels from each of the proposed groups of samples. The 3-stage triaxial consolidated undrained

Figure 9. Distribution of CBR values of 4 sample groups.

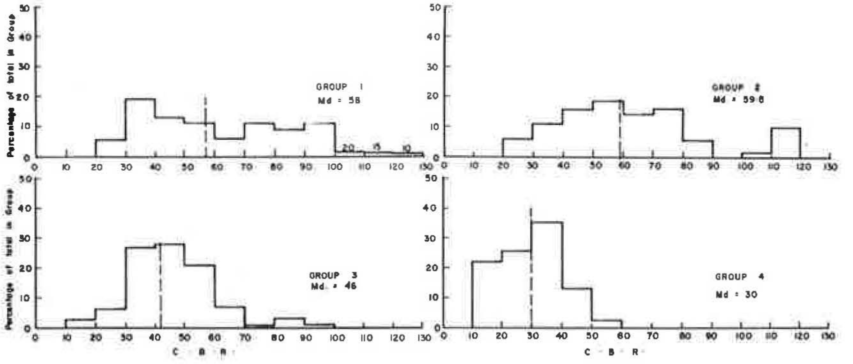


Figure 10. Relation of suitability index and soaked CBR values of 4 sample groups.

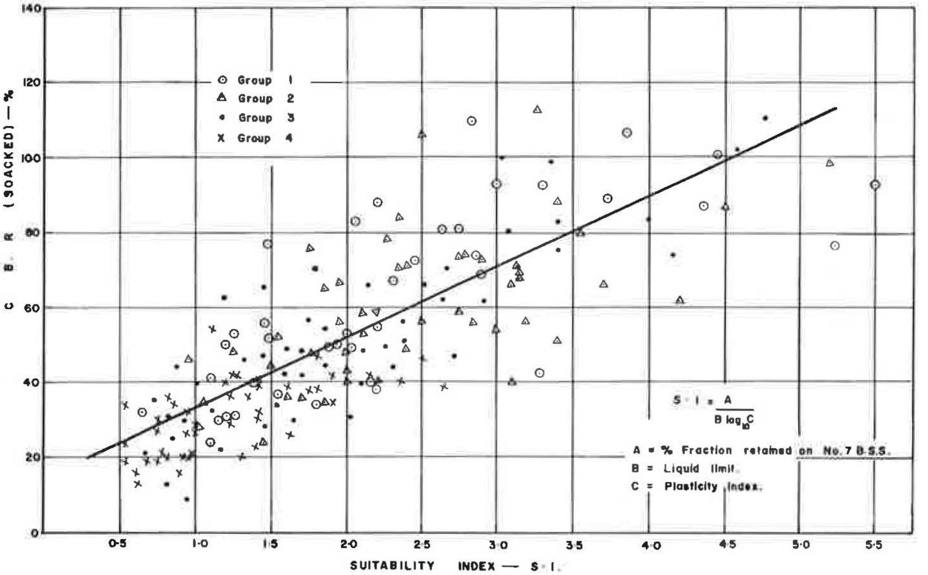
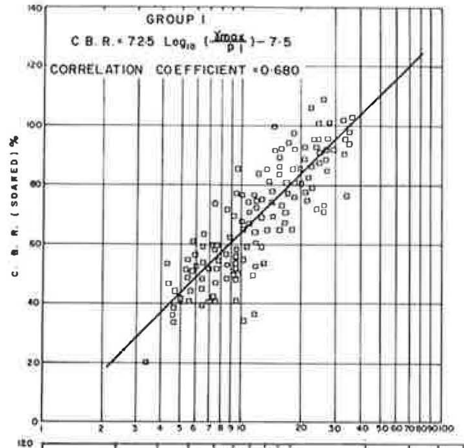
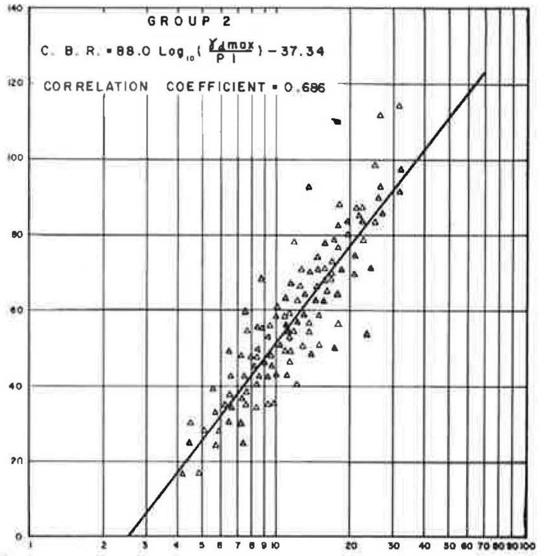
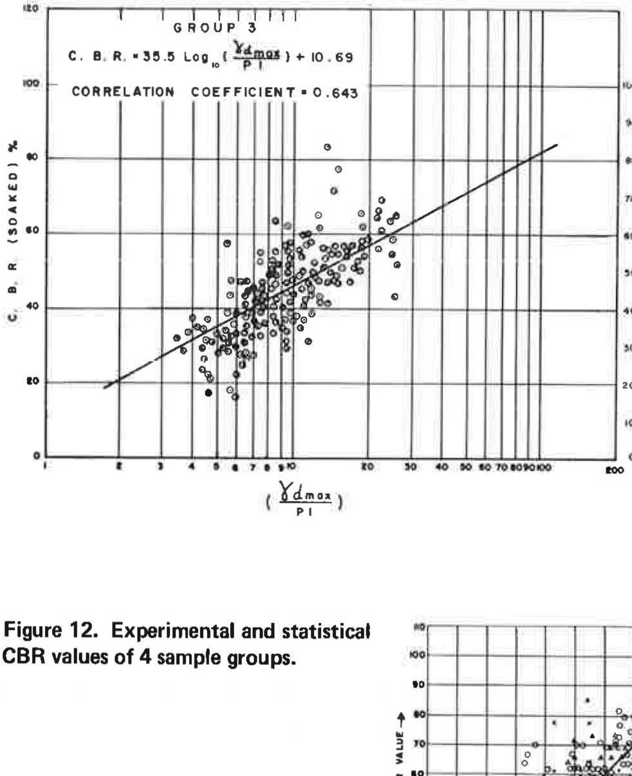


Figure 11. Relation of maximum dry density, plasticity index, and CBR values of 4 sample groups.







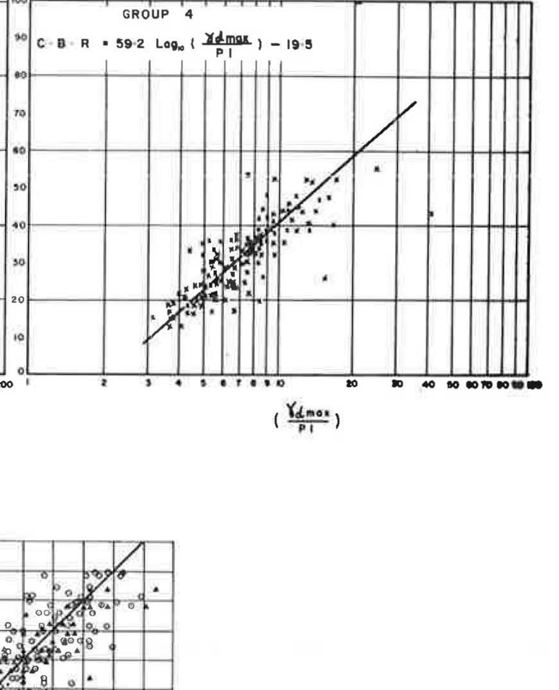


Figure 12. Experimental and statistical CBR values of 4 sample groups.

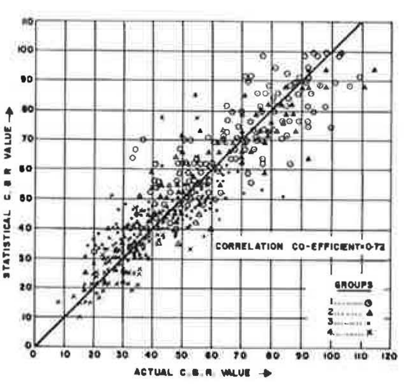


Figure 13. Typical triaxial test results of 4 sample groups.

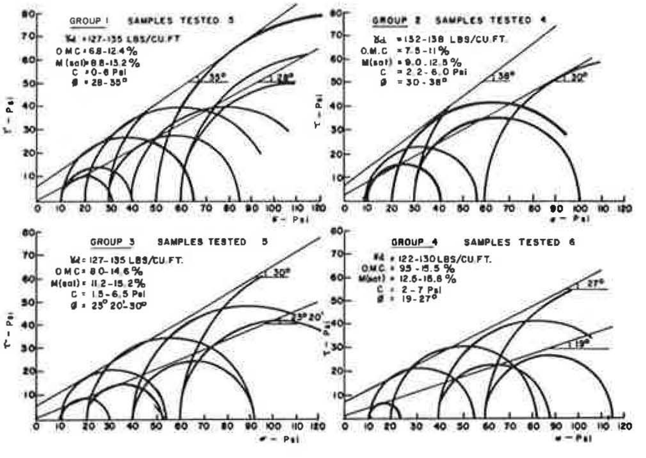


Figure 14. Actual and statistical CBR values of base gravels from trunk-road failure investigation.

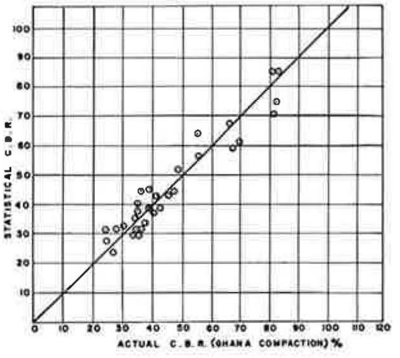


Table 3. Shear parameters in triaxial tests of 4 sample groups.

Group	Number of Tests	Maximum Dry Density (lb/ft^3)	Optimum Moisture Content (percent)	Final Moisture Content at Testing (percent)	Shear Parameters	
					C (psi)	ϕ (deg and min)
1	2	128 to 139	6.8 to 12.4	8.8 to 13.2	0.0 to 6.0	28 to 35
2	4	132 to 138	7.5 to 11.0	9.0 to 12.5	2.2 to 6.0	30 to 38
3	5	127 to 135	8.0 to 14.6	11.2 to 15.2	1.5 to 6.5	23 and 0.20 to 30
4	6	122 to 130	9.5 to 15.5	12.5 to 15.8	2.0 to 7.0	19 to 27

tests were performed on 4-in. wide and 8-in. high samples, compacted at optimum moisture content to maximum density by using Ghana compaction standard. The samples were saturated by using back pressures. The shear parameters obtained in the study are shown in Figure 13 and given in Table 3. Values of cohesion were rather low in sample groups 1 and 2 but showed an increase in sample groups 3 and 4. The angles of internal friction, on the other hand, were maximum in sample groups 1 and 2, but the values decreased progressively in sample groups 3 and 4. This confirmed the findings made in the CBR test that the relative strengths of sample groups 1 and 2 were in all the cases higher than those of sample groups 3 and 4.

FIELD INVESTIGATIONS

Failure investigations were carried out recently on trunk roads in Ghana to assess the causes of pavement failures. On the basis of visual observations of the condition of road surface, the pavements were divided into 4 groups: excellent, good, fair, and poor. Few sections having these ratings were selected for investigating the specific causes of road failures. For purposes of fair comparison and evaluation, sections were selected for the study that had similar physical conditions such as cut or embankment sections, with and without shoulders, or nature of surface drainage. Under similar conditions of road pavements, the following broad conclusions could be drawn on the performance of materials.

1. Most of the failed sections had the grading of their base gravels falling within the limits of groups 3 and 4. The sections showing least sign of distress had gradings conforming to groups 1 and 2. There were few exceptions where sections not showing any signs of failure had the gradings conforming to groups 3 and 4. Similarly, few exceptions were noted where the pavements having gravels belonging to groups 1 and 2 showed signs of distress. In all such cases, the surface drainage and the shoulders seem to have played the decisive role in their performance. For example, sections showing satisfactory behavior but having gravels of groups 3 and 4 had in all the cases shoulders 5 to 6 ft wide and surface drains provided on both sides of the traveled way. The complete absence of shoulders and inadequate drainage had in some cases affected the performance of gravels of groups 1 and 2 adversely.
2. No definite conclusions could be drawn on the range of Atterberg limits to be attributed to failed sections except that soils belonging to groups 3 and 4 had generally higher values. In a few cases, the base gravels having plasticity indexes as high as 10 or 15 showed reasonably satisfactory behavior, and this could again be due to favorable drainage conditions on the site.
3. The maximum densities obtained by using Ghana standard compaction were in all the cases in conformity with the ranges specified for different groups given in Table 2.
4. The actual and statistical CBR values using grading and the plasticity index of the samples gave significant correlation, and this is shown in Figure 14.
5. A number of failures in addition were noted to be the result of a combination of several factors such as inadequate thickness, poor drainage, or defective surfacing. These are not within the scope of this study and are discussed elsewhere.

SUMMARY AND CONCLUSION

1. The study is an extension of the work carried out earlier at the Building and Road Research Institute on the use of laterite gravels for road pavements. The present investigation was aimed at studying the factors responsible for the engineering properties of lateritic gravels. The factors studied were geology, climate, relief, and physical properties.
2. The present investigations revealed that there is a significant influence of geology and climate on the texture, the grading, and the physical and engineering properties of the material. Though the combination of all such factors produces a complex pattern of soil formations, these factors could be usefully employed as a general guide in depicting the physical properties of a material. The geology, climate, and topography had predominant influence on the physical properties in the sedentary profiles.

3. Texture, geology, and climate were used as guidelines grouping all lateritic gravels of Ghana into 4 distinct grading envelopes. The grading in turn had considerable influence on the maximum dry density achieved in the standard moisture-density test, provided the coarse gravel fractions had certain minimum strength to avoid easy breakdown of gravels.

4. Laboratory and field studies suggested the rating of the mechanical strength of the coarse fractions in laterites by using the standard aggregate impact test. Any gravels having aggregate impact values of more than 40 did not perform too well as road bases. The gravels with values of more than 40 generally are crushed and disintegrate during and after construction and tend to produce a material of fine texture likely to affect the performance of the road pavement.

5. The gravels falling in any one of the 4 grading envelopes showed a definite range of maximum densities, provided they conformed to the minimum mechanical strength values. A very significant correlation existed between the fineness index and the maximum dry density. The fineness index is the accumulative value of percentage passing the $^3/_4$-in., $^3/_8$-in., $^3/_{16}$-in., No. 8, No. 30, and No. 200 ASTM sieves divided by 6.

6. The strength characteristics of gravels at saturation were influenced by the density and the plasticity characteristics of the material. Significant correlations could, therefore, be established between log (maximum density/PI) and CBR values for samples of each group.

7. Field investigations had been carried out to check the effectiveness of the proposed grouping system. The investigations indicated that statistical assessment of CBR values at a given compaction standard could reasonably be made by using simple tests like gradings and Atterberg limits.

8. The field studies also pointed out that sections having base materials in groups 1 and 2 generally showed satisfactory behavior, whereas sections with gravels in groups 3 and 4 showed poor performance. It was also found that the mechanical strengths of the gravels in groups 3 and 4 were generally poor.

9. The present study gave a range of shear parameters for each group of gravels as determined at the maximum densities by using Ghana compaction standard. The shear parameters were obtained in consolidated undrained triaxial tests using samples 4 in. wide and 8 in. high.

10. It is considered that the study helps in understanding the nature and the properties of laterite gravels as affected by the various geologic processes. In addition, it provides a reasonable statistical method for assessing the strength characteristics of gravels from simple physical tests, such as grading and Atterberg limits. The method can assist in considerable reduction of the bulk testing of samples on a project and thus affect economy, choice of materials, and quality control.

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