Design Correlations for Kenya Red and Red-Brown Soils

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• ROAD DESIGN in Kenya is normally based on CBR data (after four days soaking), though whether this approach is the most realistic for the prevailing soil and climatic conditions has yet to be determined. There is a suspicion that standard CBR testing is unsuitable for some of the subgrade materials encountered and that modifications in the specifications for that test may become necessary.

In anticipation of a possible extensive road development program and of the introduction of cement and lime stabilization, intimate soil properties were investigated and correlationships were sought which might reduce the volume of design testing.

There have been two distinct investigations—one on moisture content conditions under sealed pavements, undertaken by the Road Research Laboratory, England, in cooperation with the Kenya Road Authority and the Kenya Ministry of Works; the other on soil properties conducted within the Ministry.

This paper concerns the latter study, aimed at ascertaining properties and determining labor-saving correlationships while keeping in mind the necessity for caution. In more general terms, it is an endeavor to build up, from nothing, a design philosophy suitable for Kenya conditions.

One important outcome was that most of the Kenya soils in which interest is now centered (that is, mainly red and red-brown soils) can only usefully be classified in a system introducing maximum density and optimum moisture content ranges. Another was that the required pavement thickness to carry a 9,000-lb wheel load (up to 450 3-ton commercial vehicles per day) can be correlated with the group index.

The classifications described and the correlationships derived can only be considered as provisional pending their confirmation by further experience.

RED AND RED-BROWN SOILS

Broadly speaking, in Kenya there are two kinds of red soils. There are the good red soils, acting in many ways as granular materials; and there are those varieties, exhibiting high volume change properties, often referred to as "red cotton" soils, inferring their physical similarity with the high-swelling desiccated "black cotton" clays.

Experience in the East had associated the former with those red soils in which the kaolinite clay mineral was present; the latter with those in which, it was said, some montmorillonite had been identified.

But so far, no kaolinite or montmorillonite has been identified in any of the red or red-brown soils (as distinct from decomposed stone and tuff) of the Kenya Highlands analyzed by X-ray or D.T.A. by the Materials Branch of the Kenya Ministry of Works. Nevertheless, there is a suspicion, held in agricultural circles, that there may be present in some red-brown, or brown, varieties a highly swelling amorphous mineral resembling allophane.

Soil studies (Robertson, Terzaghi, Lambe and Martin) pertaining to the construction in Kenya of the Sasumua Dam were possibly the first to reveal the presence of hydrated halloysite in Kenya red soils. Lambe and Martin commented on the instability of this form of halloysite, which was said to turn irreversibly to the "more plastic" dehydrated, or metahalloysite, at temperatures below 60C and partly so under the action of drying forces when the moisture content is reduced to about 10 percent (based on the dry weight of the dehydrated form). This led them to remark on the difficulty encountered in obtaining an interpretable value for the liquid limit of hydrated halloysite. What happens to the fine capillaries in the clay mineral particles on dehydration is yet to be learned.

The clay minerals locally identified in red and brown-red soils (and in lateritic *murrams**) have invariably included the presence of one or both of the halloysites. As motorists using dirt roads over these soils are well aware, the halloysite soils dry out rapidly, reaching their air-dry condition in a few hours.

The location of the halloysite samples identified suggests that for equal incidence of rainfall, hydrated halloysite is not found in Kenya below an altitude of about 7,000 feet; that is, its presence may be a function of temperature as well as frequency of rainfall. At lower altitudes, it apparently exists only as metahalloysite.

There is a clear indication that the hydrated variety is formed during the decomposition of basic volcanic tuffs containing feldspar, and the suggestion that this relatively quickly dehydrates to form metahalloysite. Exposure, as in the use of soil to form embankments, may, it appears, be sufficient for this conversion, which seemingly may occur in but a few weeks under these conditions.

Correlation studies have revealed a number of problems; as, for example, the apparent impossibility of differentiating between the two forms of halloysite soils on the basis of normal engineering data.

ROAD ENGINEERING CHARACTERISTICS

Some properties of the Kenya red and red-brown soils follow:

Though the red and red-brown soils are naturally free draining, they embrace a number of heavy clays. The —200 fraction and clay content (determined after dispersion with hydrogen peroxide and sodium hexametaphosphate) vary considerably, lying more generally between 96 and 60 percent (with occasional lower values) and 60 to 25 percent (with occasional values as low as 10 percent and as high as 84 percent), respectively.

The activity of the clay fraction varies over the wide range of 0.29 to 1.36, with one value of 2.71.

Organic matter contents of 8 percent, and even as much as 17 percent, have been recorded. In general, it would appear that values do not exceed about 4 percent and are more usually of the order of 1 to 2 percent.

The halloysite soils have been associated with an appreciable percentage of organic substances, which are believed to account for their initial water repellency, active until sufficient energy is exerted to overcome that repellency. It is, perhaps, odd that the natural moisture content of such soils is frequently so high, sometimes in excess of the optimum moisture content (Proctor), in the face of this repellency. The explanation may lie in the random orientation of the tube-like clay mineral particles, which do not lend themselves to orientation and densification as do the plate-like micelles of the more common clays.

As has previously been pointed out by Winterkorn, Lambe and Martin, *et al.*, the value of the liquid limit obtained for such soils depends on the amount of work put into the operation (which is, perhaps, not only a characteristic of these particular soils). To what extent this is due to the breaking down of the halloysite soil structure and particle aggregates and to what extent it depends on the geometry of the clay mineral surfaces is not clear. There is another possible cause. It might be, in part, due to the water repellent nature of the organic matter residues in these soils.

Kenya values, determined normally, vary between 36 and 78 with outside values as high as 91. In general terms,

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* *Murram* is a term borrowed from the literature of India. In Kenya it is rather loosely applied to any lateritic or laterized material. The murrams referred to herein are relatively soft primary or ground water laterites.

the liquid limit lies below, sometimes appreciably below, the Casagrande A line.

Plastic limits vary considerably, lying between 19 and 45 with an outside value of 55. Proctor optimum moisture contents vary between 20 and 39 percent, with one value as high as 49 percent.

A peculiarity of some soils, not explainable by whether they contain halloysite or metahalloysite, is, as has been noted both inside and outside Kenya, that the Proctor optimum moisture content is quite frequently numerically in excess of the plastic limit and, in one recorded instance, very appreciably so. The reason is unknown, but this characteristic may well be responsible for the doubt apparently existing over whether halloysite soils are good or poor soils for use in subgrade and dam construction. By way of contrast, some samples examined had, apparently, optimum moisture contents appreciably below the plastic limit values.

Maximum as well as natural densities are low, the former being more usually of the order of 72 to 94 pcf with a variety as low as 68 pcf. A small subgroup had values of from 94 to 107 pcf.

Volume shrinkage generally varies between 30 and 40 percent, but it is not known whether these soils can exert any appreciable pressure on absorbing moisture, although it is known that they shrink, in the field, on drying. From observations on road pavements, it seems doubtful if the swelling pressure is ever high.

There is a most remarkable similarity between values for the liquid limit and the field moisture equivalent which is said to characterize kaolinitic soils. Why this is so for these soils, in view of the external energy normally applied to attain the liquid limit, is not known. Values generally lie between 41 and 72 (with values as low as 30 and as high as 86) and appear to vary with the ratio of —40 to —200 fractions by some law in which the organic matter content does not appear to play a controlling part.

Some data for identified halloysite samples are given in Table 1.

CORRELATIONS AND CLASSIFICATION

Design experience and field observations had led to the suspicion that there were at least two kinds of red and red-brown soils as far as load-carrying capacity was concerned. Additionally there were, of course, such other soils in Kenya as the granular lateritic *murrams*, decomposed tuffs, sand clays, silty pumice soils, and the so-called desiccated "black cotton" clays.

The great majority of the samples examined were of red and red-brown soils and *murrams*. Although some of the data for the other materials tested fell within the correlations determined, there were

TABLE 1

CHARACTERISTICS OF IDENTIFIED HALLOYSITE SAMPLES[1]

Sample		Liq. Lim.	Pl. Lim.	Mois. Cont. (%)		Org. Matter (%)	−200 Fract. (%)	Clay Cont. (%)	Activity	pH
Composition	No.			Opt.[2]	Nat.					
Metahalloysite	1	73	35	49	50	NK	94	30	1.27	5.2
	2[3]	91	55	NK	40	16	72	19	1.55	5.3
	3[4]	62	42	33	30	1.5	92	67	0.29	5.7
	4[5]	44	27	20	NK	0.4	13	7	0.50	6.3
	5[6]	62	43	39	NK	3.2	95	53	0.36	4.8
	6	85	55	47	50	NK	NK	18	1.33	5.8
Hydrated halloysite	7[7]	50	34	28	NK	0.9	37	13	0.55	5.8
	8[7]	47	37	26	NK	0.7	23	4	0.70	5.7

[1] NK = not known.
[2] Proctor.
[3] Selected because presence of hydrated halloysite was suspected (but not found).
[4] First sample from this embankment material tested for clay mineral and organic content only; results indicated presence of hydrated halloysite and 8.1 percent organic matter.
[5] *Murram* sample.
[6] Red tea soil.
[7] Decomposed tuff (parent material for many red soils).

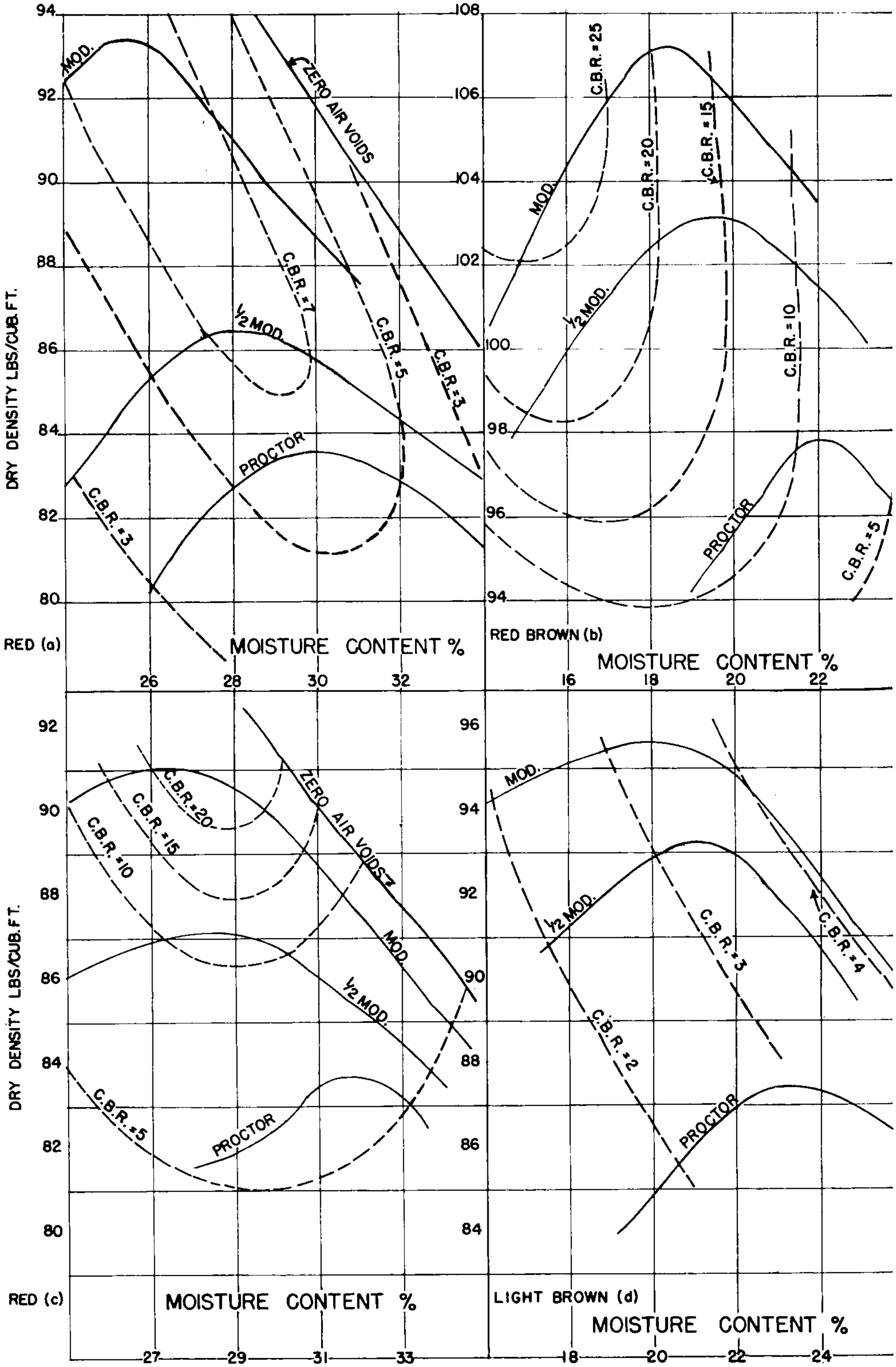
DRY DENSITY LBS/CUB.FT.
MOD.
ZERO AIR VOIDS
C.B.R.=7
C.B.R.=5
C.B.R.=3
1/2 MOD.
PROCTOR
C.B.R.=3
RED (a)
MOISTURE CONTENT %
C.B.R.=25
C.B.R.=20
C.B.R.=15
C.B.R.=10
C.B.R.=5
RED BROWN (b)
MOISTURE CONTENT %
C.B.R.=20
C.B.R.=15
C.B.R.=10
C.B.R.=5
RED (c)
MOISTURE CONTENT %
C.B.R.=3
C.B.R.=4
C.B.R.=2
LIGHT BROWN (d)
MOISTURE CONTENT %

Figure 1.

others which did not. The present paper refers only to red and red-brown soils unless specifically mentioned otherwise.

No correlations were sought for the granular *murrams*, as such, as each source would require a special investigation before the material could be used in pavement construction. Among the granular *murrams* tested, however, a number were encountered showing high maximum density, for such material, but very low CBR values for Proctor compaction. Although their test constants are not included within the ranges given for the soils described, they have been included for comparison purposes in the correlation graphs, as have also a few of the very soft (sp. gr. about 2.3) decomposed tuffs.

Correlations and an identification system were evolved in the following way:

1. For believed "typical" samples, iso-CBR charts (four days soaking) were constructed on the moisture-density curves for modified, half-modified and Proctor compaction efforts. Four of these curves are reproduced in Figure 1.
2. The charts gave a sequence of CBR patterns varying between the extremes illustrated by the first and last insets of Figure 1; that is, for from low to high swelling materials. They varied mainly in the relative position of the over-all maximum CBR value, which changed from well on the dry to well on the wet side of optimum moisture content, in the slope of the line of optimum CBR's and in the shape of the iso-lines.

From these patterns the various typical materials were grouped into a number of different kinds. The data were then considered in conjunction with the relationship between the group index and pavement thickness required by CBR values for compaction under the various compactive efforts. This enabled the number of kinds of material to be reduced to three main types—two very different materials and one having aspects common to both extremes as shown for soils X, Y and Z of Figures 2-6.

3. For each of the three soil groups there was, as shown in Figures 2-6, a correlation between group index and pavement thickness for two compactive efforts considered.

Materials belonging to the two main groups, X and Z, were red and red-brown soils, with a few brown soils, classifiable within these groups on the basis of optimum moisture content and maximum density ranges, as given in Table 2.

TABLE 2

CHARACTERISTICS OF MAIN SOIL GROUPS INVESTIGATED

Soil Type	Opt. Mois. Content (%)		Max. Density (%)	
	Proctor	Half-Mod.	Proctor	Half-Mod.
Z	16–23	14½–20½	91–107	97–112½
X (a)	23–30	20½–27	86–93½	91–99
(b)	30–39½	26–36	72½–86	79½–91
Y	13½–30½	11½–26½	80–111	88–116½

The third group, Y, represents a small number (11) of materials, of which only two belonged to the red and red-brown soils under consideration. The remainder included some black, brown, and light-brown soils and some decomposed tuffs. Unfortunately, the mineralogical composition of the members is unknown. The group represents those materials which, for some unknown reason, appear to be the weakest soils according to standard CBR testing procedure. The optimum moisture content and maximum density ranges appear to embrace both of those given for soils of types X and Z. The members of this group are only identifiable and classified by their CBR values for compaction to half-modified maximum density, which were found to be less than 7.

To complete the classification picture it was considered necessary to determine a single CBR value, for compaction to a known density and at a known moisture content, approaching half-modified maximum density and optimum moisture content, for all samples tested. This single value, considered with the typical CBR patterns, not only isolates the type Y materials, but also acts for type X and Z materials as a guide for obtaining, for

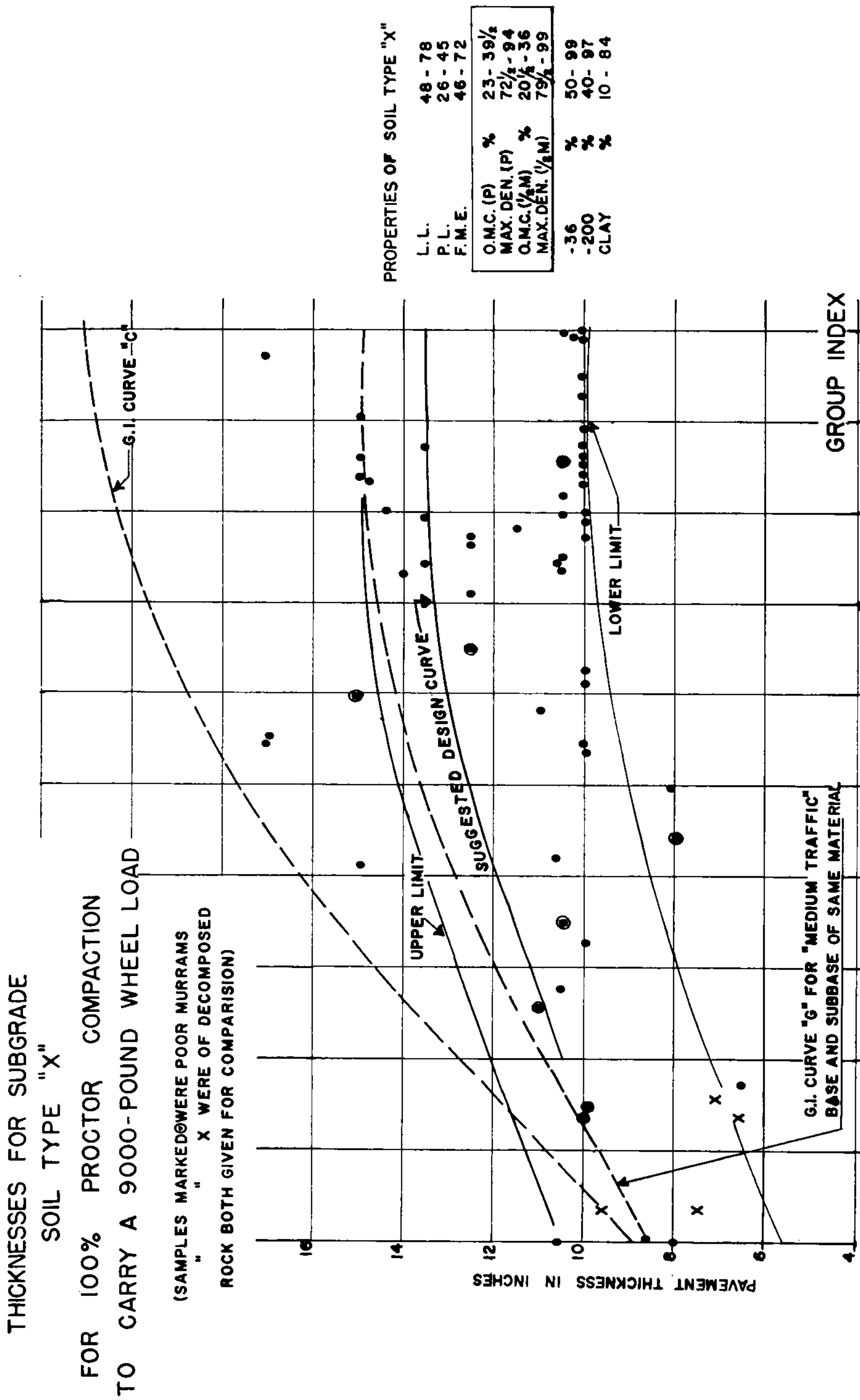
THICKNESSES FOR SUBGRADE
SOIL TYPE "X"
FOR 100% PROCTOR COMPACTION
TO CARRY A 9000-POUND WHEEL LOAD
(SAMPLES MARKED ⊚ WERE POOR MURRAMS
" X WERE OF DECOMPOSED
ROCK BOTH GIVEN FOR COMPARISION)
PROPERTIES OF SOIL TYPE "X"
L.L. 48 - 78
P.L. 26 - 45
F.M.E. 46 - 72
O.M.C. (P) % 23 - 39½
MAX. DEN. (P) 72½ - 94
O.M.C. (⅛M) % 20½ - 36
MAX. DEN. (⅛M) 79½ - 99
-36 % 50 - 99
-200 % 40 - 97
CLAY % 10 - 84
G.I. CURVE "C"
UPPER LIMIT
SUGGESTED DESIGN CURVE
LOWER LIMIT
G.I. CURVE "G" FOR "MEDIUM TRAFFIC" BASE AND SUBBASE OF SAME MATERIAL
GROUP INDEX
PAVEMENT THICKNESS IN INCHES
4
6
8
10
12
14
16
2
4
6
8
10
12
14
16
18
20

Figure 2.

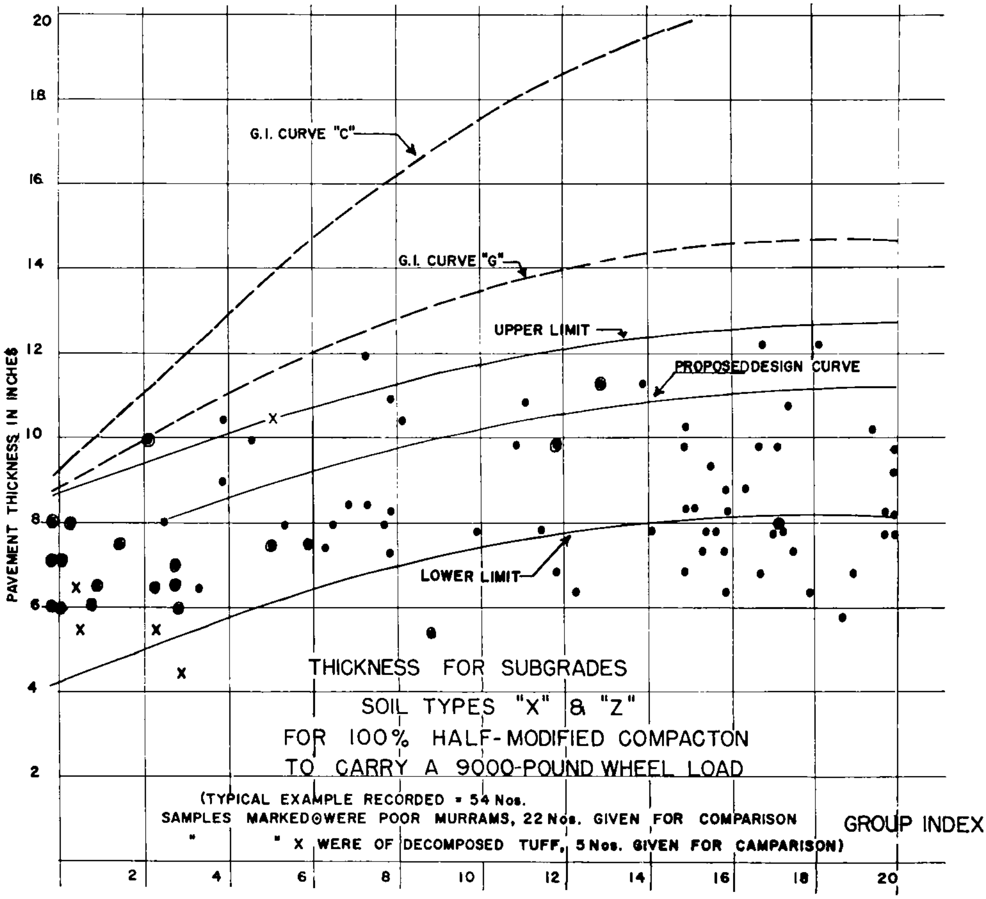

Figure 3.

any short length of road, the most economic pavement thickness from the appropriate correlation curves.

CORRELATION CURVES

The interesting features of these curves are as follows:

1. The best soils, represented by type X materials, possess a group index-pavement thickness relationship, for Proctor and half-modified compaction efforts, similar to that given by Don Steele's curve G for pavements whose base and subbase courses are constructed in the same or substantially the same material.

Both the curves for the worst soils, type Y, appear to be identical with the Don Steele thickness curve C for pavements whose base and subbase courses are constructed in very different materials.

The relationships for the intermediate materials, type Z, appear to resemble the G curve for high compactive efforts and the C curve for low compactive efforts.

The foregoing correlations refer to the results of laboratory testing and apply under the conditions prevailing during that testing.

According to Steele's curves and the work on load distribution through base courses of different quality (Herner *et al.*), the correlation curves should depend

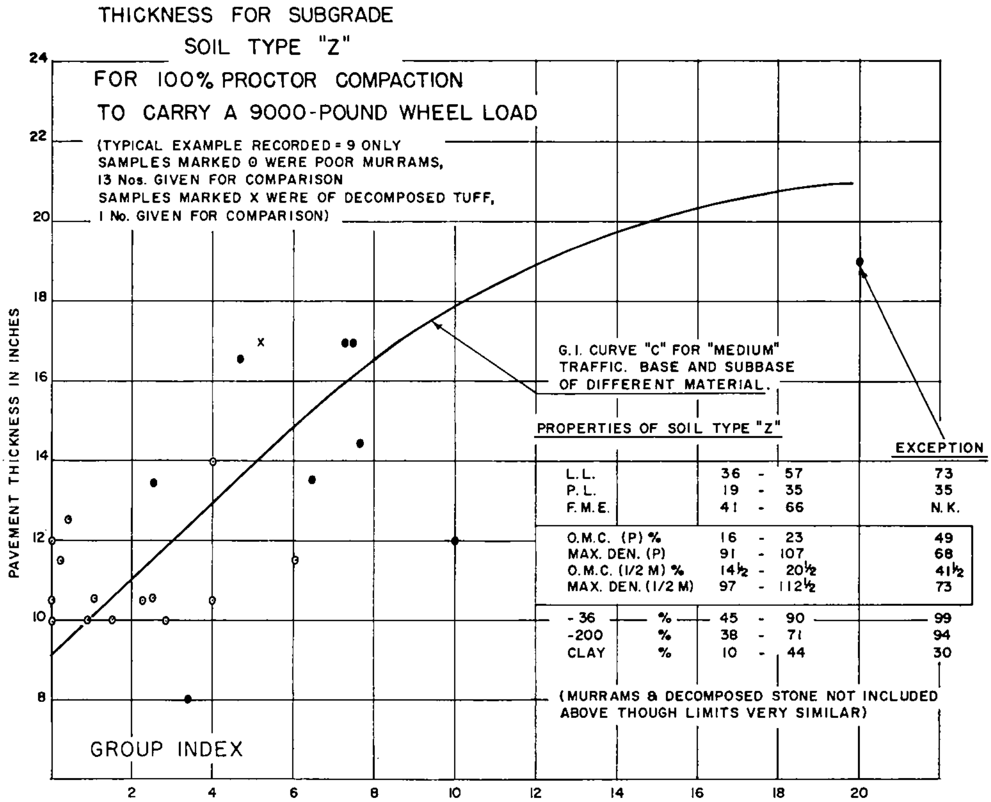

Figure 4.

not only on the nature of the subgrade material but also on the respective qualities of the base and any subbase course material—a fact which was not ignored during the development of the CBR method of design.

As the basis of the CBR method of design provides for average conditions, it would not appear necessary to modify the laboratory-determined correlationships for Kenya so long as the base and surface courses are of good quality material and are durable. That is, however, an assumption which has yet to be justified.

2. The correlations for type X material for both compaction efforts, and for type Z materials when compacted to half-modified maximum density, show reasonably clearly demarcated upper and lower limits. Although such zones are to be expected, they should not lightheartedly be ignored in favor of some kind of average curve. The pavement thickness range, for any value of the group index, indicates a difference in cost between the upper and lower thickness limits of some 40 to 100 percent. It was for this reason, as well as for identifying the type Y soils, that the single CBR determination was considered necessary. Nevertheless, as an alternative, the single-line relationships shown as proposed design lines in Figures 2 and 3 are believed to give safe and reasonably economic pavement thickness values.

3. Data derivable from the X and Z curves appear to confirm experience on pavement thicknesses vs durability, but there is some doubt as to whether all the materials falling within the Y group behave in the field as poorly as suggested

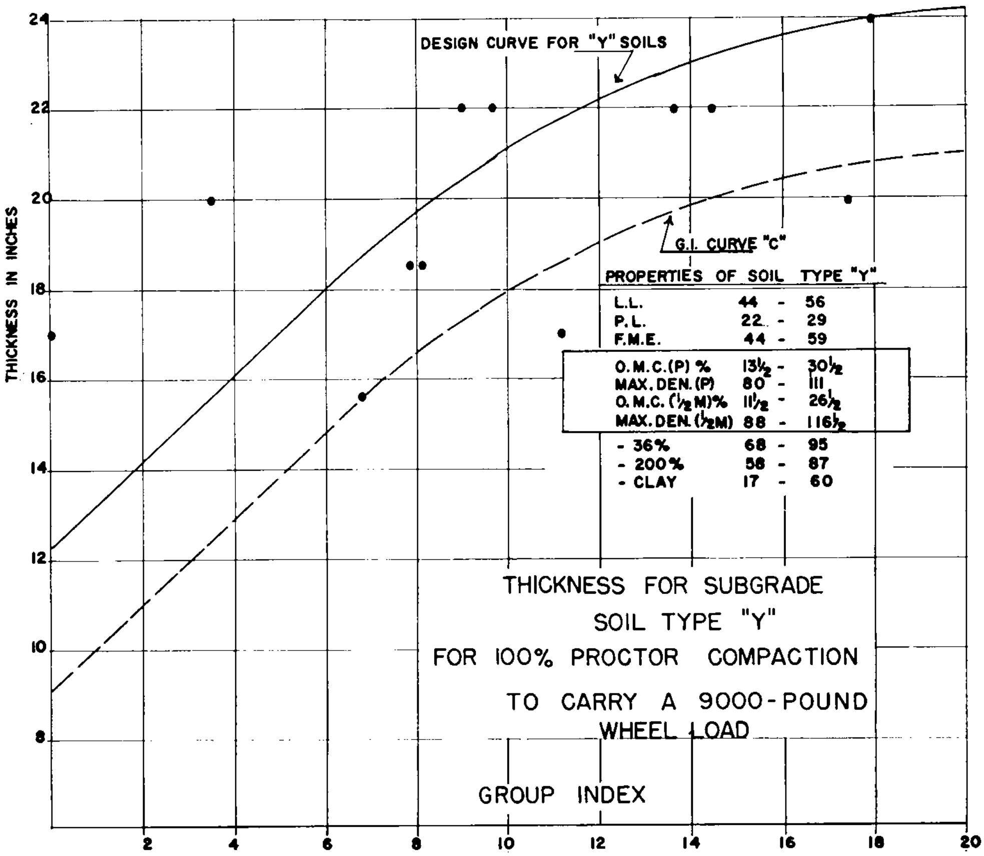

Figure 5.

by the laboratory data based on 4 days soaking.

It is known that very thin pavements carrying heavy traffic have existed over black cotton clays for 15 years or more, although it is equally well known that so far as pavement distortion and maintenance costs are concerned, they failed many years ago.

SINGLE CBR VALUES

Iso-CBR charts (some 280 points covering the *murram* and soil types encountered over the Kenya main road network) have much information to impart of a kind that would escape attention if only single CBR determinations were available.

They indicate that:

1. An error of 0.5 percent in locating the optimum moisture content when drawing in the compaction curve — or a like error in moisture content when making up a sample to optimum moisture content for CBR determination, may make a considerable over-all difference in CBR values for some materials and according to their pattern of iso-CBR lines. This difference may be as great as 50 percent or more for soils and 100 percent for *murrams*. Poor control during construction may be expected to lead to similar differences.

2. For any given moisture content of compaction, relative densities in excess of 100 percent maximum may lead to increased CBR values, as in Figure 1(c);

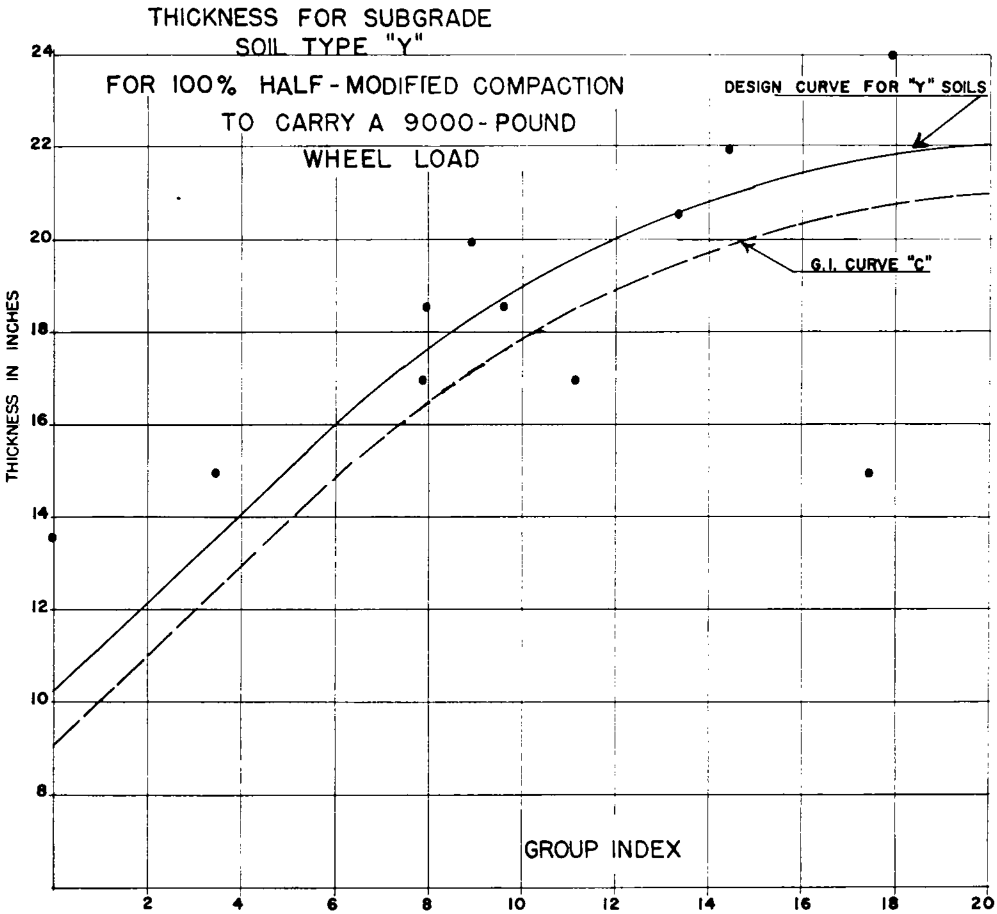

Figure 6.

decreased CBR values, as in Figure 1(a); or no substantial change in CBR values, as in Figure 1(b).

3. In general terms, an appreciable and often rapid increase in strength will occur for type X and Z soils, and especially for *murrams,* with decrease in the moisture content of compaction; and more particularly so when at the same time the compaction density is increased above Proctor maximum density, as indicated in Figures 1(b) and 1(c).

4. For a few soils and *murram* materials there is no great strength advantage achieved by compacting to maximum density for any effort in excess of Proctor—the CBR's for maximum density and optimum moisture content remain sensibly the same (that is, an iso-CBR line tends to run through the line of optimum densities). Examples were found among the type X(b) soils (see example, Fig. 1(a)).

DESIGN AND MOISTURE CONTENT CONTROL

Whenever it is considered economically possible, by experience or by site test, to compact red, red-brown soil types Z, X(a) and, with reservations, X(b) and *murrams* at half-modified optimum moisture content (about 2½ percent less than Proctor optimum moisture content) to half-modified maximum density, those requirements are incorporated into the specifications.

Compaction at optimum moisture content gives, by virtue of the way in which the correlation curves were determined, a construction moisture content tolerance of $\pm 1\frac{1}{2}$ to $\pm 2\frac{1}{2}$ percent without any loss in strength. For type Y materials this may imply a maximum permissible moisture content on the wet side of the plastic limit. When this is so, it is felt that the latter value should control the upper limit and the range should be reduced accordingly. If this is impossible, as when the plastic limit is appreciably below the Proctor optimum, the material is considered unsuitable for use.

COMMENTS ON POOR SOIL MATERIAL

Although the necessity for using poor soils in subgrade layers may not arise in the more developed regions of the world, the possibility of their use has always to be considered in the relatively poor undeveloped countries.

There is a tendency for the type Y soils, as the black clays, of the Highlands to give two forms of iso-CBR patterns—that is, of the kind shown in Figure 1(d) and a form similar in outline to that shown in Figure 1(c) but in which the iso-CBR lines are displaced more to the wet side and where the CBR values are of the same order as in Figure 1(d).

It is believed this variation in iso-CBR line shape indicates an important difference in properties between the two varieties. The swelling pressure exerted by the former, on taking up water, is believed to be appreciably in excess of that exerted by the latter. The inference from this would be that the latter soil, though very poor, might be satisfactorily used in a subgrade layer where as use of the former might give rise to considerable pavement distortion. There is some evidence in support of this belief.

Mineralogically, the two varieties will be very similar in that they will contain some clay mineral of the montmorillonite group. Surface-chemically, however, they are likely to differ in the nature of their adsorbed ions, as might be suggested by the rainfall and supported by their pH values. Although the presence of replaceable sodium leads to increased swelling of the clay micelles in the powdered form, it has the effect of masking the swelling properties of a compacted and structural montmorillonoid clay.

It is known, for example, that in parts of Burma relatively thin pavements can be constructed over the desiccated black clays (black cotton soils) crossing the annually flooded plains and that there is little subsequent distortion of the pavement surface. This is believed due to the presence of the known relatively high values of the replaceable sodium which, in that country, restricts water intake to a maximum not exceeding the plastic limit.

Some three years ago, a railway bridge embankment was constructed in black cotton clay soil near Nairobi, Kenya. There has been no obvious movement or any differential change in level of the bituminous surfacing. The embankment was designed for compaction at a moisture content 3 percent less than Proctor optimum to a density of 103 percent Proctor maximum. The actual moisture content of compaction varied between 2 and 5 percent less than Proctor optimum and, in general, the dry densities achieved ranged between 103 to 110 percent of Proctor maximum.

During the construction period a long spell of heavy rainfall occurred, but only small changes were found in the density and moisture content and then only to the depth damaged by the passage of machines.

The Kenya black cotton soils are usually slightly alkaline and it is the belief, yet to be checked, that those soils giving iso-CBR patterns similar to that shown in Figure 1(c) are a little more alkaline than those illustrated by the pattern of Figure 1(d).

Site CBR testing on black cotton subgrades under bituminous surfaces where the relative density was about 100 percent Proctor, indicated that for a lifetime of up to about 15 years, the *in situ* CBR under the pavement edges, when the shoulder material was not too permeable, was in excess of any value obtainable from any of the iso-CBR charts determined for such soils.

Nevertheless, along a 15-year-old road where such values were obtained, there is appreciable distortion; along that road it is known that the subgrade moisture content is sometimes in excess of the plastic limit, which approximates Proctor optimum moisture content.

There are, therefore, the possibilities for consideration that the best varieties of a black cotton soil are indicated by a more alkaline reaction and that such soils should be compacted at a moisture content below Proctor optimum to reduce the possibility of the maximum moisture content reaching values in excess of the plastic limit and giving rise, with time, to pavement distortion.

There is also the suggestion that the specifications for *in situ* CBR testing may require modification to eliminate the possibility of producing appreciable CBR values within a moisture content range eventually productive of plastic yield and surface distortion.