HIGHWAY CONSTRUCTION PROBLEMS INVOLVING PLASTIC VOLCANIC ASH

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Synopsis

Along the eastern shores of the island of Hawaii are soils derived by weathering of volcanic ash under conditions of continuous moisture. This has resulted in a very plastic type of soil with natural moisture content generally close to 200 percent The contained moisture is not free water and hence cannot be drained. Due to the almost continuous rainfall, the deeper layers maintain their high moisture content. The surface layers, measuring 6 to 18 in. thick, are subject to partial drying. Drying effects an irreversible change in the soil from plastic to relatively non-plastic. Thus passenger cars and light trucks can travel over the topsoil. On the other hand, the undersoil, due to its high plasticity, will not support rubber-tired traffic; equipment with caterpillar tread, however, can be used successfully within certain limitations. These limitations stem from the fact that the undersoil is thixotropic, so any undue working or manipulation of the soil causes it to lose all stability, with resultant bogging down of equipment and sliding of embankment slopes.

Excavation can be handled expeditiously by using equipment such as a dragline, taking the material out in one lift as close as possible to required grade. The freshly exposed undersoil must be quickly covered with 18 in of select rocky material to form a temporary surface (which later becomes the sub-base) for trucks hauling away the excavated material. Carryalls fitted with Athee tracks have also proven successful under certain conditions.

Embankments are best constructed in alternate layers of 5 ft. of ash and 18 in. of stable rocky material. The latter serves as a temporary stable surface over which equipment such as trucks and trac-fitted carryalls can bring up material. Compaction is dependent upon construction traffic entirely. This layer method achieves satisfactory compaction without danger of too intensive working of the material. End-dump methods can be used for relatively low and short embankments. For long embankments and for heights over 15 ft., end-dump methods result in too intensive working of the material with consequent danger of slides

In a previous paper (1) an account was given of the difficulties encountered in highway construction involving a highly plastic clay soil, derived by weathering, from volcanic ash occurring on the island of Hawaii, which is the largest of the group of islands comprising the Territory of Hawaii. The present paper is a progress report on methods that have been devised and have proven successful in overcoming these difficulties.

Hawaii (see Fig. 1) is a volcanic island with several high mountains: Mauna Kea (13,784 feet), Mauna Loa (13,680 feet), Hualalai (8,269 feet), Kilauea (4,090 feet), and the Kohala Mountains (5,505 feet). Of these, Mauna Kea and the Kohala Mountains have long been volcanically extinct, Hualalai has been dormant since 1801, while Mauna Loa and Kilauea are still active. The climatic conditions and rainfall are greatly influenced by these high mountains.

Although there have been recorded ash eruptions from Kilauea volcano within recent time (last ash eruption in 1924), most of the ash deposits found throughout the island appear to have originated from Mauna Kea (2) and for the purpose of this paper will be so regarded.

The series of ash eruptions was the last phase in the volcanic activity of Mauna Kea. Previous to this it erupted lava. Hence, along its flanks, the ash everywhere appears at the surface and is underlain by older lava flows.

In contrast, along the slopes of

Mauna Loa, Kilauea, and Hualalai subsequent lava flows have covered much of the original ash beds.

The prevailing moisture-laden winds blow inland from the northeast. Striking against the high peaks of Mauna Kea and Mauna Loa, their moisture is precipitated. Since these northeasterly, or trade, winds blow practically the year around except for comparatively short periods of southerly winds, it follows that the east side of the island is a region of heavy rainfall, which, on the whole, is well distributed throughout the year. For the purpose of this paper, the region east of the Mauna Kea-Kilauea axis (Fig. 1) will be regarded as the wet side of the island and the region west of the axis the dry side.

The rainfall in the wet region varies from 100 to well over 300 in. per year. Accordingly, the ash deposits here have weathered under conditions of practically continuous moisture. This has resulted in a type of volcanic clay soil with exceedingly high natural moisture content, as high as 560 percent based on dry weight, to quote an extreme example. In general, as it affects the problem of highway construction, the natural moisture content of this plastic type of volcanic ash may be regarded as somewhere between 100 and 200 percent.

The Wailuku River in Hilo is the dividing line between the lava flows of Mauna Kea and Mauna Loa. North of the river are thick beds of ash, measuring 20 to 30 feet in thickness along the Hilo coast. Further north, along the Hamakua coast, the thickness of the ash beds lessons to somewhat less than half this amount. South of the river the ash, although still highly plastic, seldom measures more than about 10 ft. in thickness. Moreover, large areas of it are covered by later Mauna Loa lavas.

In the dry region west of the Mauna Kea-Kilauea axis, the ash has weathered under semi-arid conditions. As a result, its physical properties differ markedly from those of the ash found in the wet region. It occurs as a fine sand or silt deposit. At least one writer has referred to it as loess (3). The material is practically non-plastic and does not call for any unusual construction techniques. This paper is confined to the plastic type of volcanic ash occurring in the wet region east of the Mauna Kea-Kilauea axis.

REVIEW OF CONSTRUCTION DIFFICULTIES

The outstanding physical properties of this plastic type of volcanic ash affecting highway construction are exceedingly high natural moisture content, high liquid limit, high plasticity index, thixotropic properties, and irreversible change from a highly plastic clay to a non-plastic sand-silt upon drying. Data concerning test results were given in the previous paper referred to above and so will not be repeated here (1).

In spite of its exceedingly high natural moisture content, cut slopes in this soil as steep as 1/4 to 1 (horizontal to vertical) have been found to be stable, but because of its thixotropic properties, it loses its consistency once it is disturbed and worked and becomes increasingly unstable the more it is worked. Cases are on record where the soil was worked so intensely, with sauerman bucket of long travel that the soil started to flow like a viscous liquid (see Fig. 2). Since it is impossible to move earth from excavation to embankment without some working of the soil, the most difficult problem was how to build stable embankments with a material that could be rendered unstable by the mere act of handling it. Adding to the difficulties are the frequent, heavy rainstorms of the region which at times amount to as much as 12 in. in 24 hr. and occasionally even more. Because of these difficulties, highway construction projects in the past were invariably behind schedule. Completion dates were as much as 12 to 18 months behind contract time. That progress is being made is attested by the fact that recent projects have been completed months ahead of contract time.

EXCAVATION METHODS

The surface of a freshly opened cut in this plastic volcanic ash is so soft and slick that rubber-tired construction

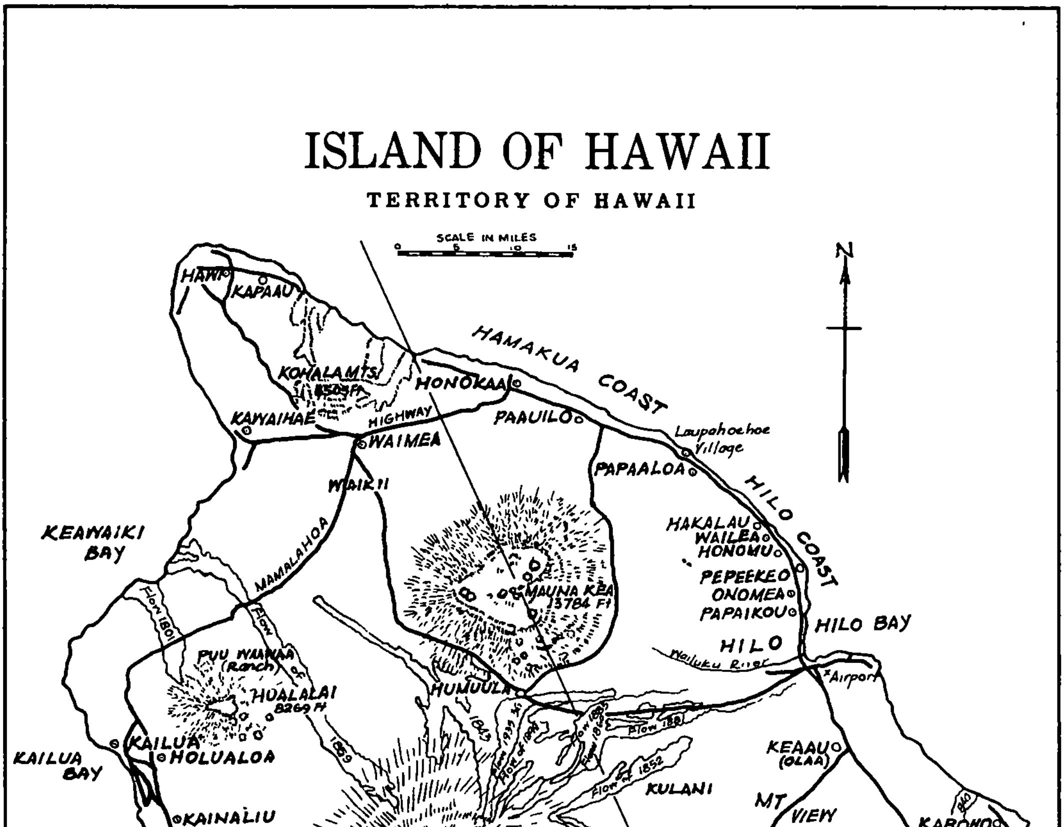
ISLAND OF HAWAII
TERRITORY OF HAWAII
SCALE IN MILES
0 5 10 15
N
HAWI
KAPAAU
KOHALA MTS.
5505 Ft.
KAWAIHAE
HIGHWAY
WAIMEA
HONOKAA
HAMAKUA COAST
PAAUILO
Laupahoehoe Village
PAPAALOA
HILO COAST
HAKALAU
WAILEA
HONOMU
PEPEEKEO
ONOMEA
PAPAIKOU
HILO BAY
HILO
Wailuku River
Airport
WAIKII
KEAWAIKI BAY
MAMALAHOA
Flow 1801
PUU WAAWAA (Ranch)
HUALALAI
8269 Ft.
MAUNA KEA
13784 Ft.
HUMUULA
Flow 1881
Flow of 1852
KULANI
KEAAU (OLAA)
MT VIEW
PAHOA
KAPOHO
Flow 1859
Flow of 1843
KAILUA BAY
KAILUA
HOLUALOA
KAINALIU
KEALAKEKUA
CAPTAIN COOK
NAPOOPOO
KEALAKEKUA BAY
HOOKENA
MAUNA LOA
13680 Ft.
Mokuaweoweo
Kilauea
Makaopuhi
KALAPANA
KAU DESERT
MAUNAKEA-KILAUEA AXIS
PAHALA
Flow 1919
Flow 1926
NAALEHU
WAIOHINU
Flow 1868
KAALUALU
LEGEND
Principal Roads
1950
Lava Flow and Date

Figure 1.

equipment, e.g., carryalls and trucks, cannot immediately travel over it. Over a period measured in weeks the surface dries partially, due to aeration. As mentioned above, this partial drying causes the ash to become less plastic. Upon complete drying, which does not occur to any great extent in the field because of the frequent rains, the originally highly plastic ash turns irreversibly to a non-plastic sand-silt. This phenomenon has resulted in the formation of a surface layer measuring 6 to 18 in. in thickness, of slightly granular texture, and decidedly less plastic than the original ash. The most valuable characteristic of this topsoil is that, except in very rainy weather, it will readily support rubber-tired construction equipment.

As far as appearances go, conditions look almost ideal for a carryall job, but experience has shown that immediately after the thin, slightly granular topsoil layer is removed and the plastic under-layer exposed, the equipment bogs down. If an effort is made to get the equipment out, the tractor, which must be of the caterpillar type, will necessarily work the soil more intensely. This intense working soon renders the soil almost semi-liquid and the entire assembly becomes immobile. Cases are on record where equipment has thus remained bogged down for days and weeks at a time. It is evident that carryall operations, except in special circumstances noted hereafter, are impractical.

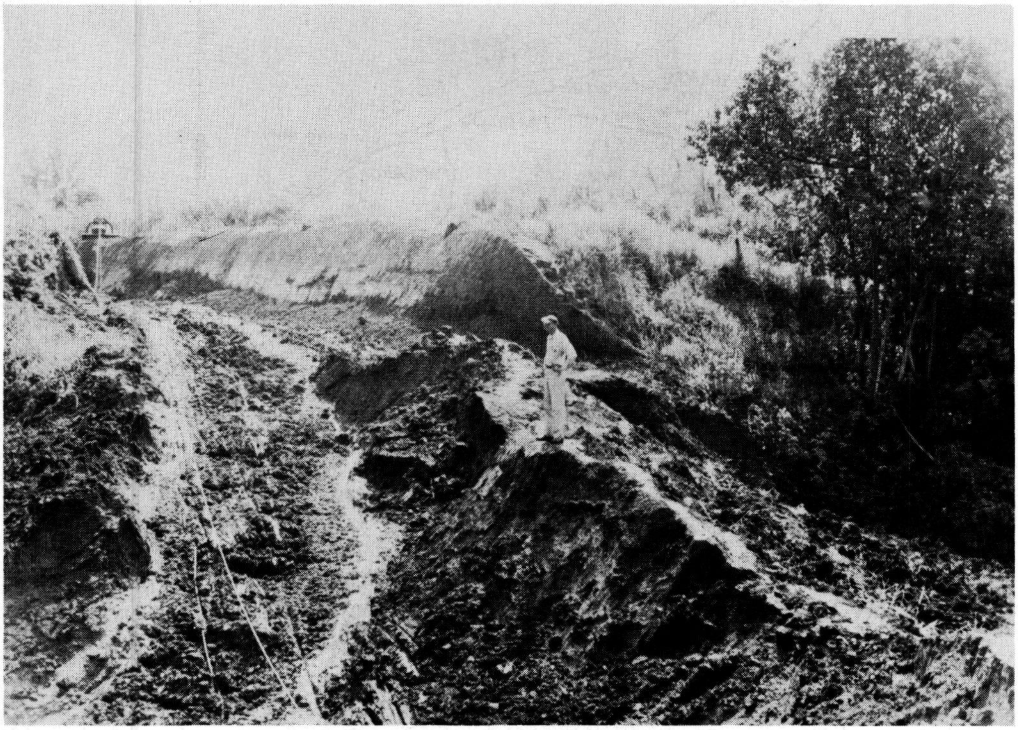

Figure 2. Embankment Slide Due to Intensive Working of Material Using a Sauerman Bucket. Note contrasting stability of cut slopes in background.

For any sizable depth of cut, the only satisfactory method is to take the material out in one lift. For the deepest cuts a dragline is the preferred piece of equipment (see Fig. 3). By staying on high ground and traveling at all times on the slightly granular topsoil it does not bog down. For moderate depths of cut a backhoe or shovel can be used. The latter necessarily has to travel over the freshly exposed surface, but experience indicates that if its movement is limited it will not bog down, unless conditions are extremely bad.

An important requisite is to follow close behind with a layer of select material. This must be spread, usually with a bulldozer, in one solid lift of 18-in. thickness. Any attempt to lay material in thinner layers is futile, since mere weight will cause construction trucks to punch through clear to the axles.

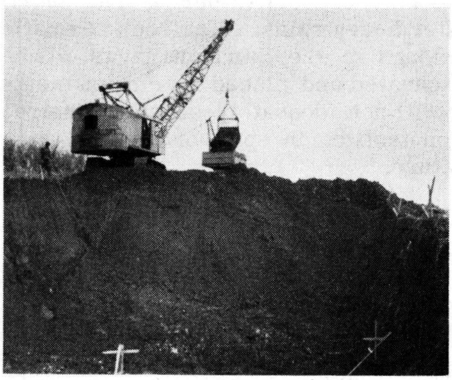

Figure 3.

The 18-in. layer of select material protects the freshly exposed soil against being worked and also serves as a base for construction operations. The best insurance against bogging down in excavation operations is, therefore, to follow very closely behind the shovel or dragline with the select material layer. This means close coordination on the part of the contractor of excavation and borrow operations for select material. Provided the two operations are properly scheduled, the method has proven well-nigh foolproof.

During construction operations spillage is more or less inevitable. Traffic churns up such spilled material, and the select material layer soon becomes covered with almost liquid mud. Fortunately, the select material being used is of such a nature that construction operations are practically unaffected. When the project is ready for fine grading the surface mud is bladed away, leaving only a thin surface film. In such thin layers the ash dries in a remarkably short time. Thus, due to rains, the surface may be very muddy in the morning but if the sun is shining it will be dusty by noon. In this dusty condition the plasticity index drops to around 6 or lower so that with a little sprinkling it serves as an excellent binder.

The conditions under which carryalls may be used are as follows: (a) the rubber tires must be removed and Athee type tracks fitted on; (b) the capacity of the carryall must not be too great (about 8 to 12 cu. yd.); (c) the depth of cut must be moderate (say about 15 ft. at the most); (d) locally the moisture content of the ash must not be too high (say below 150 percent); and (e) weather conditions must be favorable. If the conditions are as outlined above, then carryall operations can be carried on successfully (see Fig. 4). Occasional showers and streaks of material with moisture content in excess of 150 percent will not greatly affect operations. Of course, the motive power must be

Figure 4.

furnished by a large unit, such as a caterpillar D-8. Also, if the unit is of the type that has to come to a complete stop before gears can be shifted, then the engines will have to be "soupped up" to reduce the necessity of such shifting.

For very shallow cuts, bulldozers can be used to advantage. But if the unit has to move back and forth a great deal, there is some danger of the equipment bogging down.

CUT SLOPES

The fact that the material is stable in cut is indeed fortunate and as long as the ash retains its characteristic moisture content it resists the erosive action of water remarkably well. As the face of the cut is exposed to the drying influence of the sun and wind, the originally plastic ash slowly turns granular and drops onto the road shoulder, from whence it is removed by maintenance forces.

Figure 5.

The process described takes place very slowly, involves only small amounts of material at any one time, and so does not result in a major slide.

Along the sides of gulches the above described loose material from the weathering of the ash tends to accumulate and come down all at once during periods of heavy rains causing major slides. The somewhat flatter slopes of the gulch sides and vegetation tend to hold back the loose material. Hence, sidehill slopes are very vulnerable to slides, and whenever possible such locations should be avoided.

Of course the cut slopes can be benched as a precaution against slides. Figure 5, which shows a newly completed road cut, gives a good indication of the rugged nature of the terrain. How greatly construction costs will be increased by benching can be readily surmised. It was in the interests of economy, therefore, that 1/4-to-1 cut slopes were adopted as standard. Examination of old railroad cuts in the vicinity shows that such steep slopes have withstood the test of time remarkably well.

The ash cover in Figure 5 varies from 15 to 20 ft. or so. Below the ash cover is a conglomeration of cinders, lava rock of various sizes up to 5-ton boulders, rock ledges, and tufaceous material. All of the material was so highly weathered that very little blasting was necessary. The rock formation is extremely porous and there is considerable seepage from the face of the cut, especially during and shortly after heavy rains. The rock formation belongs to the Hamakua lavas. When excavated and placed in embankments, it will not adequately support construction traffic, in spite of its very rocky nature.

EMBANKMENT CONSTRUCTION

The most difficult problem in connection with this soil is the construction of stable embankments. Due to its high moisture content and its thixotropic nature, this volcanic ash cannot be compacted in the usual manner. Also, the very size and weight of modern construction equipment adds greatly to the difficulties. The use of conventional rolling equipment, e. g., sheepfoot tampers, flatwheel power rollers, pneumatic rollers, has proven absolutely futile.

First was the problem of getting the excavated material there. As long as the equipment was traveling on the original topsoil no great difficulty was encountered. Hence, placing the first layer was relatively easy. With successive lifts the difficulties increased. At times it was possible to discharge the material at the near end and depend on bulldozers to push the material forward and to level it off; but this, in effect, constituted constant working of the material, so that after awhile even the bulldozers showed signs of bogging down. Operations were then discontinued and shifted elsewhere, to be resumed when the material regained sufficient consistency.

The above end-dump method of embankment construction was heretofore a sort of standard procedure and, although feasible, was time consuming and unreliable in the case of embankments exceeding 15 to 20 ft. in height. Not only did equipment bog down frequently, but because of lack of compaction, trouble was experienced with sliding of the side slopes. So serious were embankment slides at times that it was proposed that all ash material be wasted and embankments built entirely of select rocky material. The proposal had to be rejected because of the cost.

The most expeditious and satisfactory method of embankment construction is that which has come to be known as the layer method. In this method the embankment is built up in alternate layers of 5 ft. or more of ash soil and 18 in. of special borrow material. First, the excavated material is transported to the far end of the embankment in trucks (or carryalls) and discharged there. Bulldozers then level off the material into a layer approximately 5 ft. high. When the 5-ft. layer of ash soil has been placed all the way to the near end, other dump trucks begin spreading the 18-in. layer of special borrow material beginning at the near end. This special borrow layer accomplishes two things. First, it acts as a temporary surface to provide reliable traction for construction equipment in laying down the next 5-ft. layer of ash. Second, by judicious routing of heavy construction traffic, very effective compaction is imparted clear to the edges; something that was not possible in previous end-dump methods. Also, the side slopes are carefully trimmed as the embankment is built up.

Using the layer method, embankments up to 60 ft. in height have been successfully completed and higher ones of 100 ft. and over are contemplated.

Since the adoption of the above layer method of construction, lost time due to rainy weather and to equipment bogging down has been negligible.

Some question may be raised as to the amount of compaction that can be obtained by spreading material in such relatively thick layers. Due to the high moisture content of the soil, the amount of compaction that can be imparted to it even in thin layers is limited. Beyond a certain relative compaction, a greater compactive effort merely causes a plastic displacement instead of added compaction. Numerous tests show that the compaction actually attained in 5-ft. layers is approximately equal to the compaction obtained by AASHO Method T-99 for the actual moisture content of the soil. Of course, if there should be a loss of moisture from the present natural values of close to 200 percent down to, say, below 40 percent, there will be a great shrinkage and consequent settlement, but all available data indicate that the moisture content below the first foot or so remains relatively constant so that the mass of the embankment as a whole maintains uniform moisture conditions. The best proof that compaction is reasonably adequate lies in the fact that settlement of embankments has been negligible or slight.

The top of all embankments is finished off with an 18-in. layer of select material as in cut sections.

SELECT MATERIAL AND SPECIAL BORROW

The select-material layer forms the sub-base on which the regular base and pavement are laid. Both select material and special borrow are obtained from the same pit and the two differ only in that the former is better graded and laid more carefully to grade. The special borrow is more of a construction expedient; therefore, strict requirements as to particle gradation and quality are unnecessary.

The Mauna Loa lava flows at the southern edge of the city of Hilo near the airport are just about ideal for use as select material and special borrow. For one thing, there is practically no overburden. The material is a loose fragmental form of lava resembling furnace clinker (4), known as aa (pronounced ah-ah). It is only slightly weathered, occurs in 8- to 10-ft. layers, requires no blasting, and is easily loaded with a shovel. Placed on the ash subgrade in an 18-in. layer, it not only protects the subgrade but provides the contractor with a temporary surface that assures positive traction for all his construction equipment through all kinds of rain and mud, making possible all-weather operations.

North of Hilo are the Mauna Kea lavas. These are practically everywhere covered by varying thicknesses of volcanic ash from later eruptions. In general, the older Mauna Kea lavas are not as suitable for select material or special borrow layer as the Mauna Loa lavas already mentioned. This is due to more advanced weathering. Many exposed vertical faces of apparently solid rock are seen along road cuts and sides of gulches, but these are deceiving. At the exposed face all earthy material is washed away by the frequent rains so that the rock looks clean. Back of the face the rock is mixed with earthy material, the result of weathering. The weathering is anaerobic which, together with the high organic content and continuous moisture, gives the whole a somewhat slimy consistency. Grading analyses show that the amount of fines passing the No. 200 sieve usually does not exceed 15 percent be weight. Under ordinary conditions such rocky materials make good bases and, indeed, were thus used in the old days of hand labor and light construction equipment. What makes such material unsuitable for base use under present conditions is that, due to its saturated and slightly slimy consistency, it will not initially support modern heavy construction equipment. If the material is allowed to dry out, which takes time, it makes a fairly satisfactory base, but such drying out procedures are cumbersome and unsatisfactory on contract work.

The lava flows of Mauna Kea have been classified in two great series: an older series of flows, known as the Hamakua series, and a later, less weathered series of flows, known as the Laupahoehoe series (5). The latter are the only Mauna Kea lavas that are suitable for use as select material or special borrow layer.

There is a correlation between the depth of ash cover and the age of the lava flow as expressed by the above two main series. Thus if the ash cover is less than about 5 feet or so, it is possible that the lavas belong to the later Laupahoehoe series. If the depth of ash cover is great, the chances are practically certain that the lavas, no matter how promising they appear to be, are of the older Hamakua series and therefore unsuitable for select material or special borrow use.

Satisfactory borrow pits are strictly limited to lavas of the Laupahoehoe series. Requirements are that the lava be fragmental (for easy working) and that it be only slightly weathered. However, experience shows that some drilling and blasting is necessary.

The location of suitable sites for select material and special borrow assumes greater and greater importance for projects beyond economical haul distance from the Mauna Loa lavas of Hilo.

OLDER CONSTRUCTION METHODS

In the old days of hand labor and wheelbarrows no trouble was encountered with bogging down of equipment. Sub-grades were carefully dressed to exact line and grade. It was then more or less standard practice to lay an 8-in. Telford base followed by a 2-in. rock layer to smooth off the Telford and a 2-in. asphalt-macadam surface. Construction was, in a great many cases, by stages, and the final asphalt macadam surface was not laid until many years after the first layer of rock was placed. Hence, variations from the simple 8-2-2 mentioned above are encountered but, to the best of the author's knowledge, none of the roads built prior to 1935 has a total thickness exceeding 12 in. or so.

Because both traffic and construction equipment were light in weight, it was possible to make extensive use of the above-mentioned Hamakua lavas, obtained both from road cuts and roadside quarries, as base material. Although our recent experience showed that such materials are not initially stable under heavy wheel loads, they proved successful under the then current light loads. As time passed the material gained stability, due to added compaction of both the base and subgrade, enabling the road to carry increasingly heavier loads. Such increase in load capacity by increased compaction due to traffic and time have been reported by others (6) (7). Pavement failures were remedied by superimposing additional layers, so in many sections the normal 2-in. asphalt surface measures a good 4 to 6 in. or so. Within the last two years construction traffic and regular commercial traffic has increased both in weight and density so that many sections of the older roads have deteriorated badly.

Coming down to more recent years, just before the start of our heavy construction program, it was the practice to fully complete grading operations before laying any base material, forcing all construction equipment to travel over the ash surface. Equipment was frequently bogged down and work could only be resumed after a week or so of good, dry weather which dried the surface sufficiently to turn it slightly granular as previously mentioned. Completion dates were invariably months behind contract time.

In embankment construction, end-dumping methods were standard. This was satisfactory for low embankments, but for heights exceeding 15 feet it was not only slow and difficult but often resulted in troublesome slides.

SUMMARY

The methods described in the foregoing have greatly facilitated construction operations. In particular, provision for a layer of rocky material to provide positive traction for construction equipment during grading operations has enabled the contractors to bid with more confidence.

If modern construction equipment were not so heavy, the select material layer could probably be reduced to about 12 in. For example, a D-8 caterpillar tractor is in many cases much too heavy and bogs down during unfavorable weather, while a D-6 appears to be the best all-around motive power, but it does not seem practical to specify that the contractor shall use only light equipment. For one thing, more units would be required and contractors would need to be re-equipped, since they are already stocked with the heavy equipment.

As it is, during the early stages of construction, there is a most pronounced heave of the subgrade at times, even with 18 in. of select material under the wheel loads of construction traffic. This heaving action gradually subsides as time goes on. Prior to laying the base, all weak spots are noted and the sub-base built up to a compacted thickness of 24 in. This is followed by a waterbound macadam base 4 in. thick. The whole is then finished off with a 2-in. surface course of asphalt concrete.

That our construction methods have proven successful is shown by the fact that lost time due to unfavorable weather and muddy field working conditions has been reduced to negligible proportions. As a direct result, projects are now being completed well ahead of contract time.

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LATERITE SOILS AND THEIR STABILIZATION

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Synopsis

Origin, occurrence, and correct identification of laterite rock and soil are briefly discussed. The peculiar properties of laterite soils are outlined and suggested methods of dealing with them are indicated.

Results are reported of experimental studies on four laterite soils and one intrazonal non-laterite soil, with special attention to their susceptibility to stabilization. The latter varied over a wide range Of the stabilizers used, Portland cement gave best results in some cases and aniline-furfural (2: 1) in others. The presence of organic matter seems to play a detrimental role in many cases.

The possible use of "oiled earth" properly fortified with anti-oxidants and bactericidal substances for low-cost roads in laterite areas is briefly discussed

Of the important groups of the tropical and subtropical soils of the world, the laterite soils occupy a unique place, in regard to both their extensive occurrence and peculiar properties. They are widely distributed in such areas as India, Indonesia, Indo-China, Malaya, Burma, Western Australia, Madagascar, Central Africa, the Guianas, Brazil, and Cuba (Fig. 1). From a world-wide political and economical point of view[1] study of these soils is of vital interest because: (1) they normally possess good tilth and excellent drainability, with plenty of solar energy and water available; with an adequate supply of fertilizers they are capable of excellent yields and may well be destined to contribute in a major degree to the food supply of the world; and (2) a great need exists for a suitable network of low-cost roads in these areas already in their present under-developed condition and even more so if their proper agricultural development is to proceed.

[1]See Point IV of the Truman Program, and the British plans for assisting in the economic development of Southeastern Asia and of Africa.

From a purely scientific point of view, the peculiar engineering properties of laterite soils as extreme products of soil genesis call for an extensive investigation and possible elucidation, not only for their own sake but also for a better understanding of the properties of less extreme soil types. The present work is confined to the engineering characteristics of these soils, especially those of importance in low-cost road construction.

The development of the science of soil stabilization has given a scientific footing to an understanding, though as yet more or less qualitative, of soil behavior in highway and airport structures (31). Most of the available information, however, pertains to soils of the temperate zones. That soils of the different climatic zones vary extensively in their properties is well-known. The necessity for a possible special approach to the study of the tropical and subtropical soils has been emphasized by many authors (13, 27, 32, 33).

PREVIOUS INVESTIGATIONS

Ever since the word laterite was introduced, first in geology and later