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ments. The shear tests show the strength of the undisturbed soil to be 60 to 100 pounds per square foot, and, applying these values as outlined by Dr. Leo Jerguson before the Boston Society of Civil Engineers on May 9, 1934, it was concluded that the meadow surface could be loaded to 200 or 300 pounds per square foot without inducing soil movements. This is equivalent to 4 or 5 feet of unconsolidated ashes, comparing favorably with the results of the field loading tests.

24 structures adjacent to the meadow were investigated, of which 14 represented successful foundation installations, showing little or no disturbances; nine had suffered settlements or lateral movements, and 7 of these were seriously disturbed by adjacent earth moving operations. Two principal causes contributed to the failures; inadequate capacity of the piles or soil supporting the structures, and lateral soil movements induced by excavating or filling operations.

It was generally concluded that light structures, weighing not over 300 pounds per square foot and capable of withstanding settlements, could be built anywhere on the site, while heavier structures, having distributed weights not in excess of 50% of the load already on the ground, might be built over the area of the ash dump. Bridges and other important structures should be supported on foundations extending to the firm soils underlying the clay and silt layer.

Summary and Conclusions.

1. Low areas may be safely filled to desired grades, with additional material needed to consolidate soil and surface sponge consolidations.

2. Filling to be done by dry methods, the first layer not over 4 to 5 feet in depth, or so as will not induce subsil movements.

3. Excavation of dump to be controlled to prevent subsil movements, generally limited to depth of excavation to 10 or 20 feet.

4. All areas after grading will support distributed loads up to 300 pounds per square foot, but will require soil consolidates.

5. Structures built on graded area of dump should impose distributed loads not in excess of one-half of those now present.

6. Foundations for light and permanent structures should be carried down to firm ground.

7. Filling and grading operations to be completed before structures are built, to avoid settlement due to ground movements.

No. C-3

THE RELATION BETWEEN THE CHEMICAL COMPOSITION AND THE PHYSICAL CHARACTERISTICS OF SOME HAWAIIAN SOILS

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There are some laterites of basaltic lava origin in the Hawaiian Islands which resemble clays in their plasticity, and in the properties of shrinking when dried and swelling when wetted, but which have grain sizes, as determined by the Wiegner apparatus, which are larger than those of clays, and which, if classified according to size of grain, would be placed in the group of fine silts. In the case of some of these soils the plasticity index is so large that it cannot be explained as being due to the presence of flake grains, of which there are few, or of extremely fine grains, and it appears that some other cause of the high plasticity must exist.

Chemical analyses of many Hawaiian soils which have been made by a number of chemists, mostly interested in the composition of the soils from an agricultural point of view, have shown a comparatively low silica content and a correspondingly high iron and alumina content. (Lavas and Soils of the Hawaiian Islands, by Walter Maxwell, F.T. Crowley, C.F. Eckart and E.G. Clark. Published by the Hawaiian Sugar Planters' Association, Honolulu, 1905.) (The Soils of the Hawaiian Islands, by W.P. Kelley, W.T. McGeorge, and R. Thompson. Hawaii Agricultural Experiment Station, Bulletin No. 40, 1917.) This is to be expected in a laterite. These chemists have apparently all held the opinion that some, at least, of the iron and aluminum present, is in the form of hydrates. It is possible that iron and aluminum hydrates might be present to a certain extent as gels, and the presence of such gels would sufficiently account for the plastic characteristics of the soils.

The work described in this paper was carried out for the purpose of listing the chemical compositions of some of the soils referred to, together with such of their physical characteristics as could be determined by laboratory tests, for the purpose of comparison.

Unfortunately for our present purpose, the methods of chemical analysis are such that the substances present in the soil are broken down, and finally obtained as the oxides, and it is not possible to tell with accuracy what combinations of the elements occurred in the soil; whether the basic elements were present as oxides, hydrates, hydrated silicates, or in some other combination. Further, in considering the results of a chemical analysis of a soil, it is to be remembered that there are several different methods of analysis in use, and the interpretation of the results is to be made with a knowledge of the method used in the case under consideration. The method of analysis used in the work reported herewith is essentially the concentrated hydrochloric acid digestion method which was considered to be sufficiently accurate for the purpose, since the Hawaiian basaltic soils break down comparatively easily. The insoluble residue obtained after digestion in acid contains the insoluble silica, and it may also contain manganese, titanium, phosphoric acid, and some iron and alumina. The titanium dioxide (TiO_2) content of Hawaiian soils is often from two to four per cent, and sometimes much higher; the manganese oxide (Mn_2O_4) content varies from less than one per cent to about four per cent, except in a few instances of higher

Table 1

COMPARISON OF PHYSICAL PROPERTIES OF SOILS FROM THE MARSHALL ISLANDS

Soil Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24		
Lower Limit Lead	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	
Plastic Limit	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	
Shrinkage Limit	26.0	26.0	26.0	26.0	26.0	26.0	26.0	26.0	26.0	26.0	26.0	26.0	26.0	26.0	26.0	26.0	26.0	26.0	26.0	26.0	26.0	26.0	26.0	26.0	26.0	
Plasticity Index	2.87	2.87	2.87	2.87	2.87	2.87	2.87	2.87	2.87	2.87	2.87	2.87	2.87	2.87	2.87	2.87	2.87	2.87	2.87	2.87	2.87	2.87	2.87	2.87	2.87	
Specific Gravity	2.65	2.65	2.65	2.65	2.65	2.65	2.65	2.65	2.65	2.65	2.65	2.65	2.65	2.65	2.65	2.65	2.65	2.65	2.65	2.65	2.65	2.65	2.65	2.65	2.65	
Coefficient of Expansion	1.35x10 ⁻⁴																									
Permeability Index (cm./min.)	1.0x10 ⁻⁶																									
Wetted State	1.0x10 ⁻⁶																									
Shrinkage (mm./mm.)	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	
Grain Size																										
Greater than 0.125 mm. diam.	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	
0.125 mm. - 0.0625 mm.	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	
0.0625 mm. - 0.0312 mm.	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	
0.0312 mm. - 0.0156 mm.	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	
0.0156 mm. - 0.0078 mm.	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5	
0.0078 mm. - 0.0039 mm.	(22.1)	(22.1)	(22.1)	(22.1)	(22.1)	(22.1)	(22.1)	(22.1)	(22.1)	(22.1)	(22.1)	(22.1)	(22.1)	(22.1)	(22.1)	(22.1)	(22.1)	(22.1)	(22.1)	(22.1)	(22.1)	(22.1)	(22.1)	(22.1)	(22.1)	
Less than 0.0039 mm.	()	()	()	()	()	()	()	()	()	()	()	()	()	()	()	()	()	()	()	()	()	()	()	()	()	
Apparent Chemical Composition																										
Available Phosphorus (ppm)	39.5	39.5	39.5	39.5	39.5	39.5	39.5	39.5	39.5	39.5	39.5	39.5	39.5	39.5	39.5	39.5	39.5	39.5	39.5	39.5	39.5	39.5	39.5	39.5	39.5	
Fe ₂ O ₃ (ppm)	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	
CaO (ppm)	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	
Loss on Ignition (ppm)	27.7	27.7	27.7	27.7	27.7	27.7	27.7	27.7	27.7	27.7	27.7	27.7	27.7	27.7	27.7	27.7	27.7	27.7	27.7	27.7	27.7	27.7	27.7	27.7	27.7	

The soil will not take during an immersion of one week; some specimens were oven-dried, others merely air-dried.

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content. (Composition of Hawaiian Soil Particles, by W. T. McGeorge. Hawaii Agricultural Experiment Station. Bulletin No. 42. 1917.)

As to the physical tests, the lower liquid limit was obtained by the early method of holding the dish in the hand when jarring, a Casagrande apparatus not being available. The plastic limit was obtained by rolling out the specimen on absorbent paper, and the shrinkage limit was obtained by Dr. Terzaghi's indirect method, which requires the volume of the shrunk specimen to be obtained by displacement of mercury. The grain size distribution was determined by the Wiegner apparatus. The expansion index and the permeability index were obtained from the results of a standardized compression test, using Dr. Terzaghi's compression apparatus.

The physical and chemical characteristics of the soils examined, are stated, as far as obtained, in Table 1.

Soils 7 and 8 are the typical gray sedimentary laterites, of the sort which have given a great deal of trouble as foundation material. Buildings which rest on soils of this sort are likely to settle in rainy weather, especially on the wetter side; if of concrete, they usually crack. The soil expands and contracts as it is alternately wet and dry. The plasticity index in each is fairly high, and the insoluble residue (silica) content is about 38 per cent. Soil No. 5 represents a material not as fully weathered as Soils 7 and 8, and the difference shows in both the plasticity index and the chemical composition. These three soils especially show whatever justification there may be for the thought that the plasticity may be connected with a low silica content and a relatively high iron and alumina content. The data given on the other soils are useful mainly to illustrate the different stages of disintegration, and the effects of different compositions. Soils 3 and 4 are soils which appear to have undergone much chemical change but not much disintegration. They are probably the result of the decomposition in place of debris slopes which accumulated below the cliffs of the valley. Although a grain size distribution was not obtained, the soils were of rather coarse grain; the lower liquid limit is high, but the plastic limit is also high. Soil No. 10 is of coarse grain, the particles resembling fragments of glass, as seen through the microscope. When disintegrated, these volcanic cinders produce a very fertile soil; this specimen resembled a dirty sand. Soils 12 and 13 are quite similar, Soil 12 having been deposited in its final location by Nature, and Soil 13 deposited by a dredge. They represent the final accumulation of mud below sea level, which is the result of the mixture of materials derived from lava and coral rocks. The data on tuffs from Diamond Head and Koko Head are useful only as general information. These materials usually appear crumbly and apparently ready to form soil, but prove to be quite resistant to disintegration. They had been presumably deposited below sea water, and later elevated, and during the procedure had become well compacted. These tuffs support a certain amount of vegetation, but by no means a luxuriant growth.

The generally low content of insoluble residue exhibited by all of the specimens, which is largely made up of silicon dioxide (SiO_2), is characteristic of the Hawaiian soils. Together with this goes the relatively high iron and alumina content. The evidence as to the connection between this iron and alumina content and the plasticity of the soil, is unfortunately inconclusive, but that there is such a connection is at least indicated by the meager data already obtained.

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