Title	Mineralogical Study of "Masa" with Special Reference to the Effect of Compaction
Author(s)	ORIGUCHI, Ryoji
Citation	Journal of science of the Hiroshima University. Series C, Geology and mineralogy , 9 (2) : 349 - 360
Issue Date	1990-07-20
DOI	
Self DOI	10.15027/53118
URL	https://ir.lib.hiroshima-u.ac.jp/00053118
Right	
Relation	

Mineralogical Study of "Masa" with Special Reference to the Effect of Compaction

By

Ryoji ORIGUCHI

With 9 Tables, 17 Text-figures

ABSTRACT

Abstract: Weathered granitic rocks called "Masa" are commonly developed in the Chugoku district, southwest Japan, and for the construction of a dam, Masa has been used as the core materials of rock fill type dams. This paper deals with quantitative examination of the degree of weathering, compaction and pre-crushing effects and permeability of natural state of Masa at five locations in the district. Special attentions were paid on mineralogical studies to elucidate the effects of pre-crushing and pre-compaction as well as on the interrelations of soil constants. Among the engineering soil constants of Masa, natural moisture content and content percentage of fine grains less than 74 μm (P-74) have been confirmed as effective barometers for the degree of weathering, i.e., at each investigated area, the value of P-74 varies characteristicaly according to the weathering degree of Masa. The compaction properties of natural state of Masa depend also on weathering degree and are proved to have intimate relation with maximum dry density (ρdmax) and optimum moisture content (Wopt), i.e., the former becomes smaller and the latter greater as weathering proceed. On the other hand, fine grained Masa subjected pre-crushing have higher ρdmax and lower Wopt compared with those of natural state. This means that physical and/or mineralogical properties of soil grains of Masa have changed to those with resistant against high compaction energy.

Existence of maximum value of dry density (ρdmax) was confirmed with increasing pre-crushing times. That is, the compaction density conversely lowers when the pre-crushing energy are excessive. This is probably caused by the fact that the specific surface of fractured quartz and K-feldspar increase due to crushing resulting relative decrease of matrix with which the interstices of soil grains are usually filled. Furthermore, arrangement of voids in the compacted Masa exhibits no particular orientations. This property surely increases the safety of dam concerning permeability, since the compacted Masa shows no weak direction. Finally, practical usefulness of Masa as core materials were discussed based on the results obtained.

CONTENTS

I. INTRODUCTION

In granitic rocks distributed widely in the Chugoku district, weathered granitic soil, called "Masa" is commonly developed (Kashiwagi, 1963: Kakitani, 1974 and 1975: Kohno, 1984). Masa, is being utilized as core materials for rock fill type dams, as it is easy to compact, due to the appropriate grain size distribution from coarse to fine grains. The required shear strength and imperviousness as core material can be obtained by controlling moisture content and rolling compaction. For the dam construction, it is necessary to supply a large volume of core materials not far from a dam site. In addition,

environmental problems and economization should be also considered. Accordingly, it is often necessary to use not only weathered Masa developed near the surface but also less weathered "Masa" in relatively deeper layers for effective utilization as core materials. A great deal of effort actually goes into assuring the quality of Masa as core materials, by using empirically technical methods such as blending little weathered Masa with Masa and heavy machine working in order to improve the imperviousness.

Effects of pre-crushing of Masa on the compaction mechanism in relation to permeability have not been studied systematically up to the present. Moreover, the study should be concerned with the constituent rock-forming minerals as well as with soil grains. Safety of dam will be confirmed based on such fundamental researches. Up to the present, the variation of dry density as a function of compaction has mainly been studied in relation to the optimum moisture content (e.g. Proctor, 1933). In the case of natural state of Masa, the maximum dry density (ρdmax) becomes lesser and optimum moisture content (Wopt) becomes greater with decreasing grain size caused by compaction (Matsuo and Fukumoto, 1977a). However, the variation of compaction properties caused by the pre-crushing involves problems which can not be explained only by the change of grain size distribution. Studies based upon mineralogical data including those of clay minerals will be important for further clarification of Masa. It is also necessary to quantitatively assess the degree of weathering of Masa to ensure the compaction effects and to confirm the permeability according to the degree of weathering.

This paper deals with mainly the dependence of degree of weathering on the compaction effects of various types of Masa in the Chugoku district, by examining correlations among the engineering soil properties. Special attentions were paid on the effects of pre-crushing on the compaction properties based on the minealogical studies.

Acknowledgments

guidance. Finally, Mr. Joji Koishikawa, President of the Chuden Engineering Consultants Co., Ltd. gave me the opportunity to make this study and provided a great deal of assistance.

II. Enginering Soil Properties and Degree of Weathering of "Masa"

Among various technical methods to asses the dam environment, the vertical shaft method can provide the most useful data concerning the natural state of Masa. In this chapter, various soil properties such as permeability obtained through vertical shaft as well as those of residual Masa will be examined in relation to the compaction offects and degree of weathering.

A. Investigation Locations and Topographic and Geological Outlines

The locations selected for the present research are as follows; 2 locations in Hiroshima prefecture, 2 in Okayama prefecture and 1 in Yamaguchi prefecture, respectively where mainly granitic rocks are distributed (Fig. 1). These locations were selected because the geology and the type of granite are more or less different with each other. The same methods of investigation and tests were performed at each place, so that data comparison was available. The locations, topographic and geological features are outlined as follows:
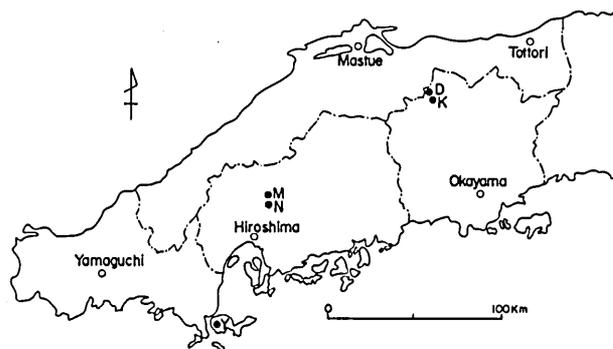
Fig. 1. Location map of the investigated areas. M, N, D, K and Y are Myojin, Nabara, Doyou, Kambadani and Yashiro dams, respectively.

1. Location M (Myojin dam)

This location for core material of Myojin dam, is at Nabara, Kabe-machi in the northern area of Hiroshima-city. The Myojin area situates at the most upstream part of the Nabara river in the O-ta river system. Geographically, the area is a low-relief surface developed at 500–550 m elevation. This surface corresponds to the south-west extension of the Kibi-Plateau which is developed widely in the central part of Hiroshima Pref. with elevation range of about 400–600 m (Kaizuka, 1950). The core materials of the Myojin dam were taken from the surrounding biotite granite with medium and coarse grains belonging to the Hiroshima granitic rocks. Paleozoic sediments are distributed as roof pendant in part of the surrounding mountain peaks (Yoshida, 1962: Ogata et al., 1978).

2. Location N (Nabara dam)

This location of the Nabara dam is approximately 4 km south of location M. Geographycally, the area are composed of hills of about 200–300 m elevation and the surface which is the northern edge of the lower surface corresponding to the Setouchi surface (Kaizuka, 1950). The geology of the area are biotite granite with medium to coarse grains, belonging to Hiroshima granitic rocks similar to those of location M.(Yoshida, 1962: Ogata et al., 1978).

3. Location D (Doyou dam)

This location for core material of the Doyou dam is at Doyou, Shinjou village, in the most northern part of Okayama Prefecture and is the most upper stream of the Doyou river of the Asahikawa river system. The area

situates in the southern part of the Chugoku mountains and represents, geographycally, old age features with mild mountain figures having a repeated medium-relief surface at about 800–900 m elevation. The geology of the area is composed of granite porphyry, belonging to the San-in granite giving a remarkable contact metamorphism to the surrounding gneiss and tuffacious rocks (Kanaori and Saito, 1979).

4. Location K (Kamba valley)

This location was one of the proposed site for core materials of the Doyou dam, located in the so-called Kanbadani, about 4 km south-south east from location D. The area is composed of gently sloping mountains of 450–600 m elevation. The host rock is bionite granite of the San-in granite (Kanaori and Saito, 1979).
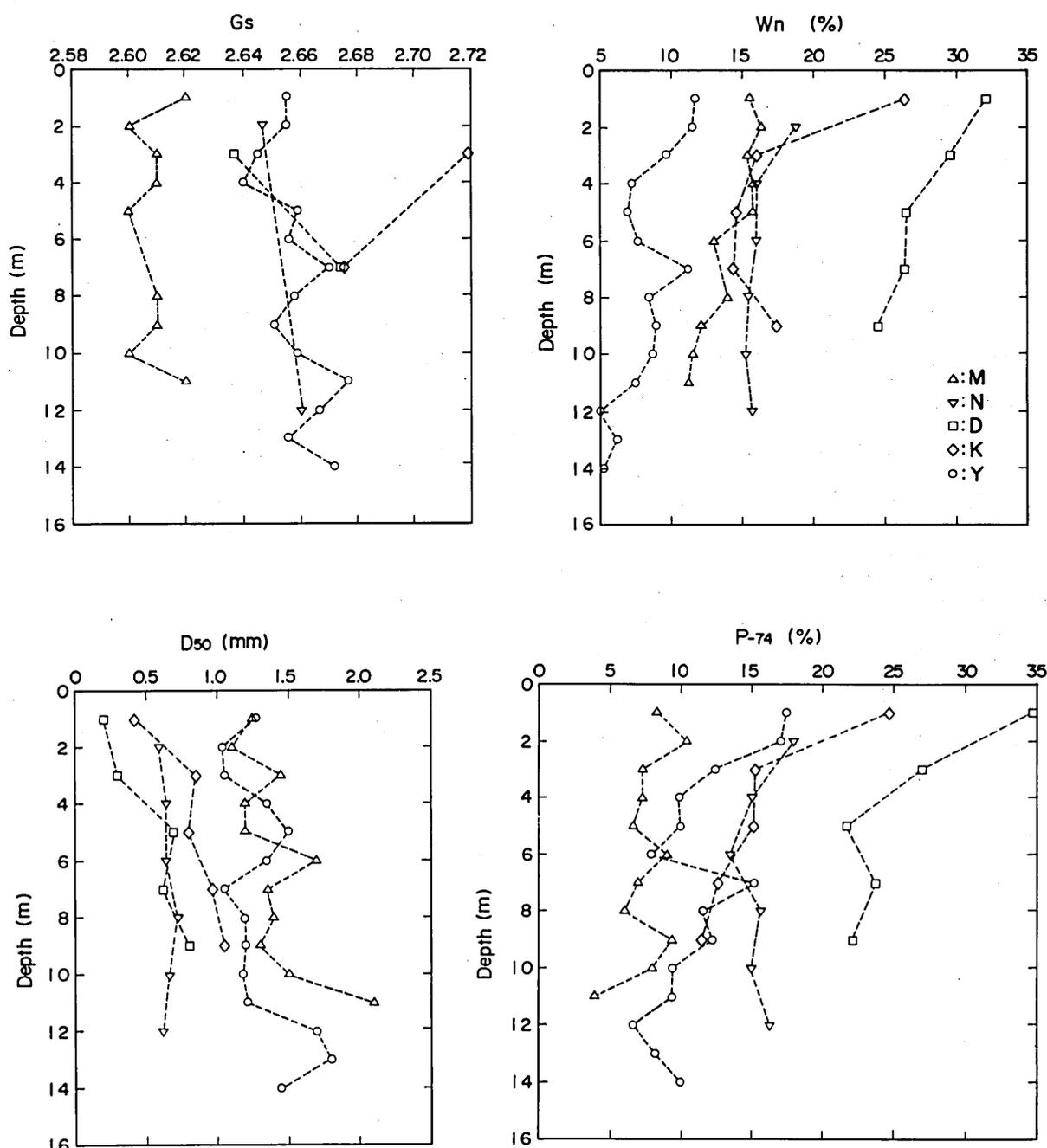

FIG. 2. Relationships between soil constants and depth from the surface obtained in the residual "Masa". M, N, D, K and Y are the same to those of Fig. 1.

5. Location Y (Yashiro dam)

The Yashiro dam is at Higashi Yashiro, O-shima-machi, Yamaguchi Prefecture. Geographically, the area situates on the north-east foot of a mountains which runs from the north-west to south-east with summit surfaces of about 500 m elevation, running south-east to north-west. The elevation of the area is approximately 200 m. Gneissose granodiorite, belonging to the Ryoke granitic rock is commonly developed in this area (Okamura and Nureki, 1962).

It should be mentioned that Masa, weathered granite soil, characteristically well develops in the intermediate surface corresponding to the Kibi plateau surface, and the low-relief surface such as lower surface of the Setouchi surface in the granitic rock region of the Chugoku district (Kohno, 1984). All of the 5 locations mentioned above are located on low and medium-relief surfaces, where Masa is sufficiently available for the dam construction.

B. ENGINEERING SOIL PROPERTIES OF RESIDUAL MASA

In the vertical shafts at the 5 investigated locations, the true specific gravity test of soil particles (JIS A 1202), moisture content test (JIS A 1203) and grain size analysis were performed according to the JIS rules on the specimens of natural state Masa. Samples were collected from the surface to the depth with several tens cm intervals. All of these tests can be carried out easily and economically. In addition, by the sand replacement method, density tests (JIS A 1214) were also performed in the vertical shafts at locations D, K and Y. The relationship between some soil constants and the degree of weathering will be mentioned in this section.

1. Natural moisture content

As shown in the representative examples (Fig. 2), the natural moisture content (Wn) has a tendency to increase toward the ground surface at each location. It has been pointed out by many researchers that void ratio (e) obtained from density tests could be an important barometer for the degree of weathering (e.g., Matsuo and Nishida, 1966). The relationship between "Wn" and "e" indicates a peculiar correlation at each location, as shown in Fig. 3. In all locations, with increasing "e" value (the greater the degree of weathering), "Wn" increases, which means that "Wn" is effective as a barometer of the degree of weathering. However, "Wn" of D is greater than those at locations K and Y for the same value of "e", indicating high water retentivity of the Masa at D location.

2. Grain size distribution

The mean grain size obtained from the integrated grain size distribution curve (50% grain size: D50) has a general tendency to become smaller toward the surface at each location, as shown in the representative example of Fig. 2. Therefore, the value of D50 is considered as a effective barometer for representing variation of grain size distribution of the host rock as weathering proceed. Further, the percentage content of fine grains less than 74 μm (P-74) has a general tendency to increase toward the ground surface at each location as shown also in Fig. 2. The value of P-74 can also be used as a indicator of the grain size of the soil particle. Thus, in this paper,

examination will be made based mainly on the values of D50 and P-74, and/or the ratio of the two as grain size characteristics. D50 and P-74 of natural state Masa at each location indicate a peculiar correlation as shown in Fig. 4. At location D, however, variation of D50 is greater than that of the other locations, especially in the region where P-74 is less than 20. Thus, D50 and P-74 must be taken into account when arguing from the view point of grain size properties, i.e., the relative degree of weathering of Masa. To be noted is that the relation between "e" and D50 shows a peculiar correlation at every location, but the relative degree of weathering can not be assessed (see, Fig. 5). However, the value of P-74 at each location shows linear relationship with the value of e indicating the intimate relation between P-74 and the relative degree of weathering. Therefore, P-74 can be reasonably used as a barometer of the relative degree of weathering. Moreover, simple method to measure P-74 has been established (JSF T 22–1971). The value of P-74 is useful as a shortcut in determining the relative degree of weathering.

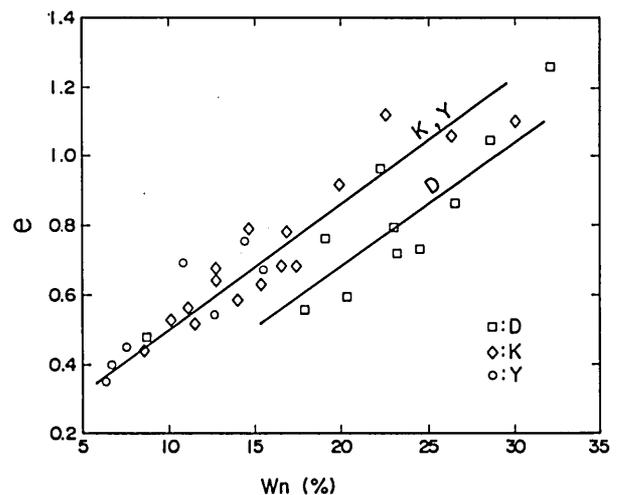

FIG. 3.   Relationships between natural moisture content (Wn) and void ratio (e). Note that each area has its own characteristic relationship.
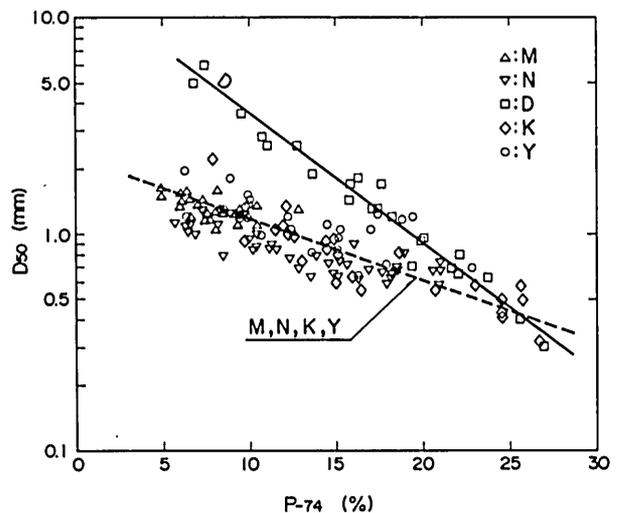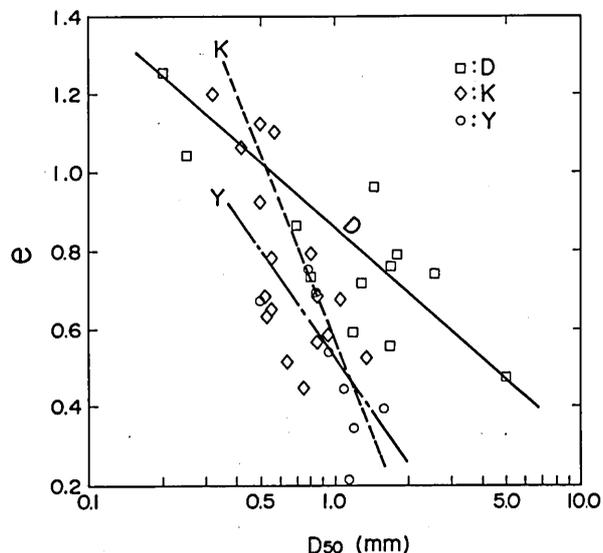

FIG. 4.   Relation between P-74 and D50. Significance of the P-74 and D50 is described in the text.

FIG. 5.   Relation between D50 and e.

3. Relationship between P-74 and the natural moisture content, Wn

Fig. 6 shows relationship between P-74 and Wn. As is seen in the figure, Wn is relatively larger at locations D and M than those of K, N and Y for the same value of P-74. Natural moisture content related intimately to the water retentivity strongly reflects the void structure, which is the complicated results of leaching of the host rock and the formation of alteration products, i.e., clay minerals. According to Aoyama et al. (1977), the void of non-disturbed "Masa" can actually be divided into two types; a relatively great voids between the constituent grains, and a micro-fractures in the constituent minerals such as quartz, plagioclase and biotite. They also reported that amount of fractures whose size is less than 0.1 μm reaches to approximately 15% of the whole voids in
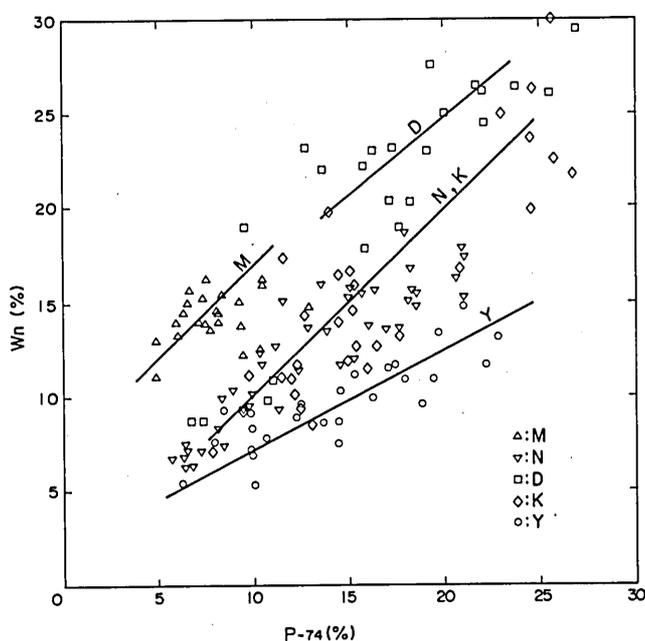
FIG. 6.   Relation between P-74 and Wn. Note that natural Masa of the respective area is distributed along certain line.

the extensively weathered Masa. Furthermore, Takahashi and Tanaka (1984) have pointed out that the water retentivity of "Masa" greatly depends upon the voids caused by rapid weathering and also on the formation of secondary clay minerals. When the constituent soil grains are relatively fresh such as river sand, it is not necessary to consider the void within soil particles. Therefore, water retentivity depends directly on the specific surface of whole soil grains. In other words, the retentivity depends upon the grain size distribution, and independent of the constituent minerals. In the case of Masa, however, the relations between Wn and P-74 vary considerably even within the same location, and each location has its own characteristics. Weathering has not been studied from a view point of the characteristics of the grain size distribution, i.e., P-74 and Wn. However, the present results indicate that the two parameters show significant correlation. That is, under the condition of relatively greater moisture content, the voids increases for the same value of P-74 as in the case at location D, (Figs. 2 and 4). It is to be noted that the voids are mostly within the soil grains. The relation between Wn and e of location D indicate the larger water retentivity compared with that of other locations.

C.   COMPACTION PROPERTIES AND PERMEABILITY

A compaction test was performed for the natural state of Masa sampled from the vertical shaft at each location by the method of JIS A 1210, 1.2-C. The maximum grain size of all examined specimens was always 9.52 mm. The standard compaction energy (1Ec) of the first JIS method is defined as follows; 25 times of compaction were applied for one layer using a 2.5 kgf rammer dropped from 30 cm height, and, as a total, 3 layers were compacted resulting total energy of 5.6 kgf·cm/cm^3. Accordingly, 2Ec in this paper, means a energy of twice the JIS, i.e., 50 times×3 layers (11.2 kgf·cm/cm^3), and 3Ec means 75 times×3 layers (16.8 kgf·cm/cm^3), respectively.

Fig. 7 shows the representative result of the compaction test. As shown in the figure, the optimum moisture content (Wopt) corresponding to maximum dry density (ρdmax) is in the range of 12 and 18% showing certain characteristic value for each specimen. In the region of high moisture content, all curves approach gradually to the "zero air void curve". In the region of low moisture content, on the other hand, each specimen shows their own characteristics. Remarkable example is the curve of M specimen indicating decreasing tendency of ρd with decreasing moisture contenet. Therefore, it may be suggested that dry density of the compacted specimen varies reversely against the compaction energy, in the low moisture region. Relationship between ρdmax and P-74/D50 (the latter is considered as a barometer of the degree of weathering) is shown in Fig. 8. As shown in Fig. 8, a systematic linear relation is observable, i.e., the greater the values of P-74/D50 the smaller the ρdmax. In other words, with increasing weathering, ρdmax decreases gradually. Wopt has also a significant correlation with P-74/D50. Such dependency was already pointed out by Matsuo and Fukumoto (1977a). However, no research has been done concerning the value of P-74/D50 which has a close correlation with ρdmax
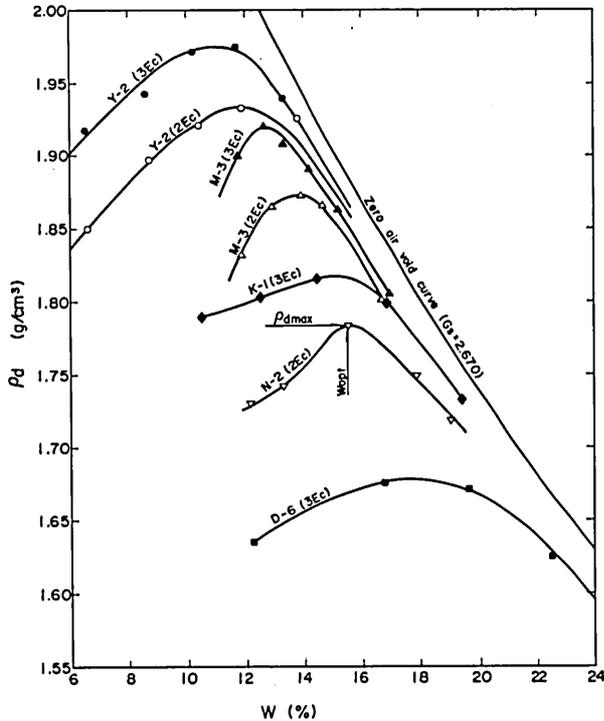
FIG. 7. Representative compaction curves. Each specimen has own particular values of ρdmax and Wopt (see text).
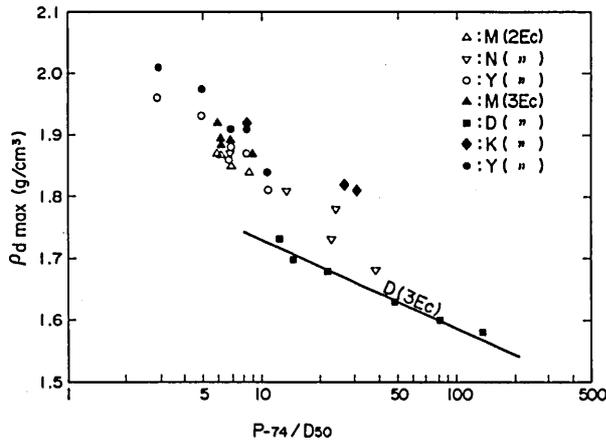

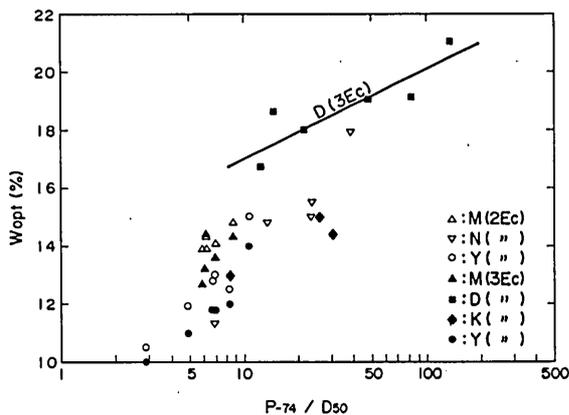FIG. 8. Variation of maximum dry density as a function of P-74/D50.

FIG. 9. Variation of optimum moisture content as a function of P-74/D50.

and/or Wopt for the same Masa. For the same value of the compaction characteristics (P-74/D50), ρdmax of D specimens is relatively small under the same compaction energy, whereas that of the other 4 locations is not distinctive as shown in Fig. 8.

Fig. 9 shows relation between P-74/D50 and Wopt. As is seen in the figure, each location has its own characteristic values, especially those of location D whose Wopt is considerably large. The relations found in Fig. 9 suggest intimate relation between P-74 and Wn of residual Masa (cf. Fig. 6). This relation leads to that of intimate correlation between Wn and Wopt. Concerning the value of P-74/D50, low ρdmax and high Wopt of the D specimens strongly suggest the void development in the soil grains as was already described in the previous section. Intimate relations among P-74/D50, ρdmax and Wopt (Figs. 8 and 9) provide possible estimations of the values of ρdmax and Wopt based on the value of P-74/D50. This relation can be practically useful in the preliminary investigation during the compaction process

III. VARIATION OF COMPACTION PROPERTIES AND PERMEABILITY DUT TO PRECRUSHING

Soil grains of Masa are easily crushed by the external forces such as remolding and compaction during the dam construction processes. Changes of grain size due to the breakage process will influence greately the physical properties such as compaction and permeability (e.g., Fukumoto, 1972; Matsuo and Fukumoto, 1976a, 1976b and 1977b). In this chapter, variation of compaction properties caused by pre-crushing will be quantitatively examined.

Three kinds of specimens were prepared for this experiments, i.e., natural state of Masa and loosed Masa after compaction with 2Ec and 3Ec energies, respectively. All specimsns were subjected to compaction with 2Ec and 3Ec energies, and the effects of pre-crushing on the permeability and some other soil constants were examined. Fig. 10 shows the effects of pre-crushing on the value of P-74, grain size characteristics. As is seen in the figure, P-74 of pre-crushed specimen is larger (about 3~4%) compared with that of natual state. The increased amount is almost constant regardless of the value of P-74 of natural state. With respect the variation of compaction properties, maximum dry density (ρdmax) of pre-crushed specimen is always greater than that of natural state as is shown in Fig. 11. The difference between the pre-crushed and natural state does not have a strong relation with the compaction energy, i.e., 2Ec and 3Ec. The optimum moisture content (Wopt') of pre-crushed specimen is always smaller than that of natural state (Fig. 12). For the variation of permeability, the minimum permeability coefficient of pre-crushed specimen is smaller than that of natural state and the variation of permeability does not depend on the value of P-74 and the compaction energy. All of these results indicate that the compaction density and imperviousness of Masa have been improved by the processes of pre-crushing. On the other hand, weatherd refined state of Masa tends to have a lesser ρdmax and a greater Wopt. This tendency can also be recognizable by comparision of Fig. 10 with Figs. 11 and 12 in relation to the value of P-74. It should be
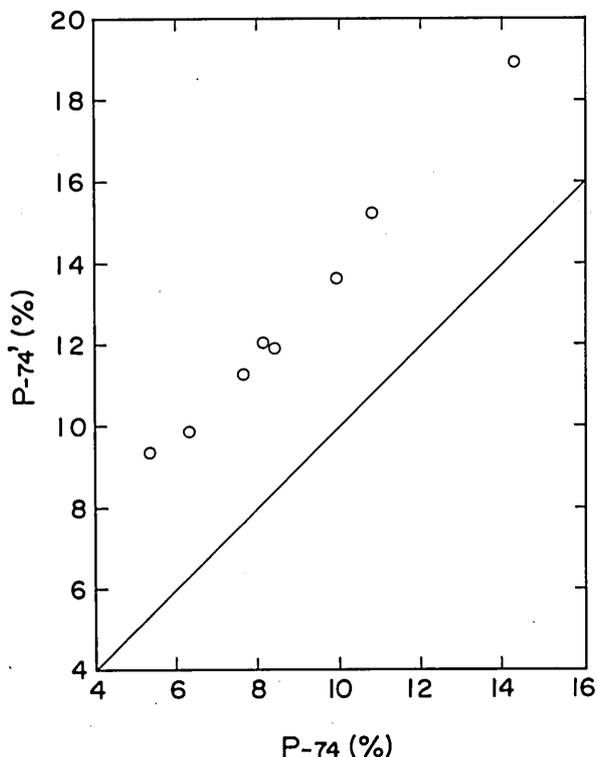
FIG. 10.   Variation of P-74 before (P-74) and after (abscissa) the first compaction (see text).
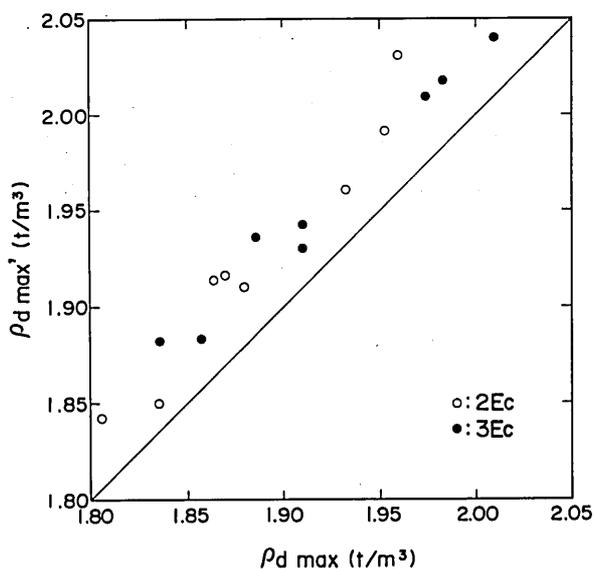

FIG. 11.   Variation of maximum dry density before (ρdmax) and after the breakdown process (ρdmax'). Note that the breakdown process yields high density soil.

noted that ρdmax of the pre-crushed specimen is greater and Wopt is smaller than those of natural state.   That is, the tendency reverses the variation direction of the grain size distribution caused by compaction.   The effect of pre-crushing has scarcely been examined.   However, no matter how the soil grains become finer, by being weathered or being crushed, variation of the compaction properties caused by pre-crushing completely reverse the general tendency of natural state of Masa.   This is probably caused by the fact that the previous examination is concerned only with soil constants, suggesting the necessity of the investigation from a view of mineralogy.
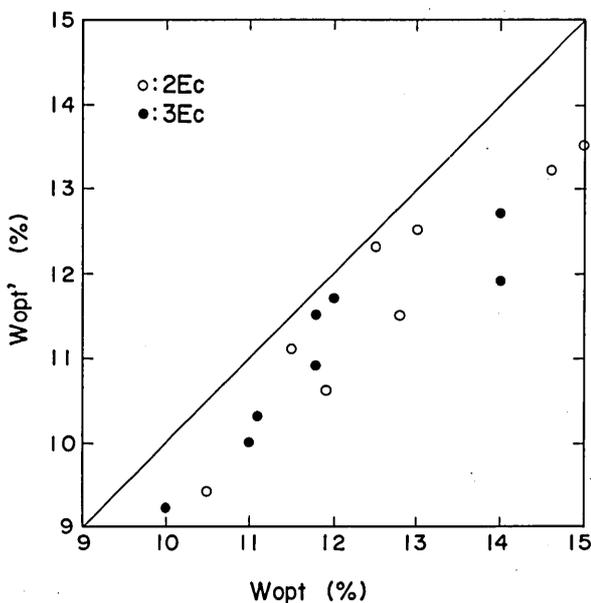

FIG. 12.   Variation of optimum moisture content before (Wopt) and after the breakdown process (Wopt').   See text.

IV.   VARIATION OF MINERALOGICAL CHARACTARISTICS
CAUSED BY PRE-CRUSHING

In the previous Chapter, it was confirmed that the compaction density and imperviousness of the natural state "Masa" can be improved by the process of pre-crushing.   In this chapter, variation of the constituent minerals will be clarified by means of the thin section observation on the compacted soil and natural state of Masa under the polarization microscope.

Thin sections were made both in the horizontal (H) and vertical (V) directions against the compacted axis for the specimens compacted by 1Ec and 3Ec and for natural state of Masa sampled at location M (A) and for the pre-compacted specimens subjected to 30 times of falling from 1.5m high (B).   Grain size distribution, D50, ρ dmax, Wopt and Kopt of these specimens are summarized in Table 1.   As seen in the Table, specimen B is more finer state than specimen A.   Compared with A, B has greater ρdmax, aller Wopt and Kopt under the same energy of compaction.   Under the low magnification conditions, 500 points were observed for each thin section using a mechanical stage.   Under the microscope, two types of grain were distinguished, one is single grains composed of one mineral surrounded by matrixes and/or voids and the other is composite grain composed of different kind of minerals.   The main results are outlined in the following;

a)   Constitutent minerals

Variation of constituent minerals of the compacted Masa is summarized in Table 2.   The amount of matrix in B appears to increase in comparison with A.   Increase of matrix is also confirmed with increasing the compaction energy, and the fact agrees with the result of the grain size examination as indicated in Table 1.

b)   Shape and mean diameter of constituent grains

The shape of the single and composite grains is represented by b/a (a: length, b: breadth, measurement limit=0.1 mm) and the results are summarized in Table 3.   Single grain (single mineral) shows no particular

TABLE. 1. REPRESENTATIVE SOIL CONSTANTS OF THE EXAMINED SPECIMENS (SEE TEXT).

Specimen No.	Grain size distribution (wt. %)					D_{50} (mm)	Pd_{max} (g/cm³)	Wopt (%)	kopt (cm / s)
	2.00mm >	2.00 ~0.42	0.42 ~0.074	0.074 <	0.005<				
A—0Ec	40.0	36.5	13.0	10.5	2.5	1.45	–	–	–
A—1Ec	37.5	36.4	14.1	12.0	3.2	1.30	1.734	16.3	2.7×10^{-5}
A—3Ec	32.6	37.4	15.6	14.4	4.6	1.10	1.813	14.7	1.1×10^{-5}
B—0Ec	33.0	39.6	14.3	13.1	3.6	1.20	–	–	–
B—1Ec	35.2	36.7	13.9	14.2	4.1	1.20	1.780	15.6	2.2×10^{-5}
B—3Ec	29.5	39.7	14.3	16.5	4.7	1.00	1.856	13.9	4.8×10^{-6}

TABLE. 2. MINERAL COMPOSITION OF THE EXAMINED SPECIMEN.

Specimen No.		Mineral constituent (%)						
		quartz	K-feldspar	plagioclase	biotite	others	matrix	void
A—1Ec	H	25.4	25.4	0.2	5.0	3.2	29.0	11.8
	V	37.6	22.4	0	4.4	3.6	21.8	10.2
A—3Ec	H	32.6	19.6	0	2.8	0.8	36.4	7.8
	V	32.2	23.4	0	3.0	0.8	33.6	7.0
B—1Ec	H	26.2	20.6	0	2.6	0.2	28.6	21.8
	V	33.6	21.0	0.2	4.2	0.8	32.8	7.4
B—3Ec	H	26.2	28.0	0	2.2	0.6	35.2	7.8
	V	32.6	22.0	0.6	3.2	1.0	33.2	7.4

TABLE. 3. AVERAGE FORM OF MINERAL AND SOIL GRAINS OBSERVED UNDER THE MICROSCOPE.

Specimen No.		Average form of mineral and soil grains (b/a)						composite grain	void
		single grain			composite mineral				
		quartz	K-feldspar	biotite	quartz	K-feldspar	biotite		
A—1Ec	H	0.57	0.58	0.51	0.60	0.64	0.41	0.67	0.58
	V	0.64	0.56	0.56	0.60	0.64	0.77	0.67	0.49
A—3Ec	H	0.66	0.67	0.68	0.73	0.69	–	0.67	0.56
	V	0.63	0.72	0.75	0.66	0.70	0.61	0.64	0.58
B—1Ec	H	0.62	0.68	0.58	0.69	0.67	–	0.71	0.63
	V	0.63	0.63	0.60	0.65	0.61	0.58	0.66	0.50
B—3Ec	H	0.64	0.68	0.55	0.65	0.65	–	0.69	0.66
	V	0.73	0.65	0.57	0.63	0.66	–	0.68	0.61

TABLE. 4. AVERAGE GRAIN SIZE IN THE COMPACTED SPECIMEN.

Specimen No.		Average grain size (√ab mm)						composite grain	void
		single grain			composite mineral				
		quartz	K-feldspar	biotite	quartz	K-feldspar	biotite		
A—1Ec	H	0.71	0.90	0.38	1.61	1.65	0.32	2.13	0.76
	V	0.84	0.75	0.34	1.60	1.57	0.66	2.48	1.08
A—3Ec	H	0.80	0.87	0.61	1.23	1.41	–	1.87	0.68
	V	0.86	0.98	0.56	1.84	2.01	0.57	2.65	1.31
B—1Ec	H	0.83	0.87	0.37	1.36	1.31	–	1.82	2.01
	V	0.76	0.85	0.41	1.83	1.82	0.22	2.49	0.82
B—3Ec	H	0.61	0.85	0.32	1.34	1.24	–	1.66	1.37
	V	0.94	0.92	0.37	1.39	1.49	–	1.93	0.82

shape variation between A and B, with the values in the range of 0.5 to 0.7. Mean diameter of the pre-crushed composite grain (B) is smaller than that of A under the same compaction energy (Ec), as shown in Table 4. The most distinctive outcome in the Table is that the mean diameter of the composite grain observed in the H direction is smaller than that of V direction, for the same specimen and the same compacted energy. This fact can be interpreted as that soil particles are arranged along the direction perperdicular to the compaction axis.

c) Preferred orientation of soil grain and void

The long axis direction of the composite soil grains in the compacted section is summrized in Fig. 13. As shown in the figure, the long axis direction of soil particles reveals no preferred orientation as a whole, indicating random arrangement of the particles. The long axis direction of voids have various orientations against the compaction axis (Fig. 14).

d) Mineral constituent of soil grain

Constituent minerals of the compacted soil grains were examined and the ratio of a single mineral grain to the total volume was measured. For each mineral, the individuality is greater in the direction of H than that of V direction. The single mineral grains are mainly dispersed along the horizontal direction during the compac-
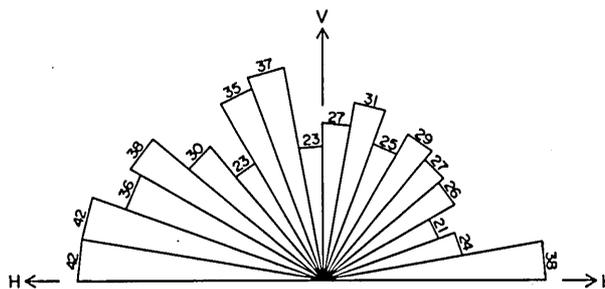

FIG. 13. Prefered orientation of soil grains measured in the long axis.
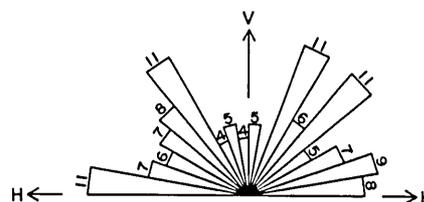V: parallel to the compaction axis.
H: perpendicular to the compaction axis.

FIG. 14. Prefered orientation of voids in the compacted soil.

TABLE. 5. DEGREE OF INDEPENDENCY (%) OF THE MAIN CONSTITUENT MINERALS IN THE COMPACTED SPECIMEN (SEE, TEXT).

Specimen No.		quartz	K-feldspar	biotite
A—1Ec	H	70.4	62.0	92.0
	V	57.6	33.3	90.5
A—3Ec	H	85.8	72.3	100
	V	52.7	44.0	85.7
B—1Ec	H	83.0	63.1	100
	V	66.7	55.2	90.5
B—3Ec	H	74.4	66.3	90.9
	V	73.7	56.1	92.9

tion. The difference of the individuality between A and B (Table 5) is most probably the main reason of the high compaction density of the pre-crushed Masa.

e) Fractures in minerals

Many fine fractures are developed in the constituent minerals, mainly in quartz grains, as indicated in Table 6. Fractures observed in mineral of specimen B roughly coincide with the optical boundary of minerals compared with those of specimen A under the same compaction energy, as shown in Tabele 7. That is,both sides of a fracture have different crystallographic orientation with each other.

TABLE. 6. FRACTURE FREQUENCY (%) OF THE MAIN CONSTITUENT MINERALS IN THE COMPACTED SPECIMEN.

Specimen No.	single grain			composite mineral		
	quartz	K-feldspar	biotite	quartz	K-feldspar	biotite
A—1Ec	34.0	27.7	16.7	46.7	41.9	0
A—3Ec	36.0	10.1	25.0	51.0	23.9	0
B—1Ec	37.8	15.1	9.4	45.6	26.0	0
B—3Ec	22.6	17.0	8.7	45.8	9.8	0

TABLE. 7. FREQUENCY OF FRACTURES (%) RELATED DIRECTLY TO
THE CRYSTALLOGRAPHIC BOUNDARY.

Specimen No.	single grain			composite mineral		
	quartz	K-feldspar	biotite	quartz	K-feldspar	biotite
A—1Ec	47.2	76.5	14.3	67.9	88.0	0
A—3Ec	61.2	71.4	50.0	76.9	45.5	0
B—1Ec	45.1	63.6	0	76.2	61.5	0
B—3Ec	45.2	35.3	0	68.2	66.7	0

V. VARIATIONS OF COMPACTION DENSITY CAUSED BY CRUSHINGS, AND MINERAL CONSTITUENTS

The compaction density of "Masa" generally increses in accordance with pre-crushings. However, an exact description of the relationship between the two factors has not been clarified up to the present. In this chapter, variation of the constituent minerals of soil grains caused by the process of crushing will be examined by observation under the stereoscope and with the x-ray powder diffraction method.

A. VARIATION OF COMPACTION DENSITY CAUSED BY CRUSHINGS

Natural state of "Masa" collected from locations M and N was first compacted using a 2.5 kg rammer, and then, loosed. The loosed specimens were compacted again by the same method and under the same compaction energy. The variation of the dry density and of the grain size distribution were examined as functions of pre-crushing and compacted energy. The dry density (ρ dmax) increases proportionally with increasing compacted times (Fig. 15). It should be noted that the two curves have a maximum value (ρ dmax). This means that the most optimum times of pre-crushing is different between M and N. To examine the compaction properties of "Masa". The fact will be important. As similar characteristics, over-compaction has been known in other sediments and/or rocks (Justin et al, 1947). The grain size distribution of the specimens of M and N advances in the finer direction with increasing the pre-compacted times regardless of ρ dmax. In addition, the content of fine grains of 5 μm or less increase significantly. The fact that specimen N contains more coarse grains of above 0.84 mm than specimen M corresponds nicely with the fact that their optimum crushing time is distinctively different with each other.
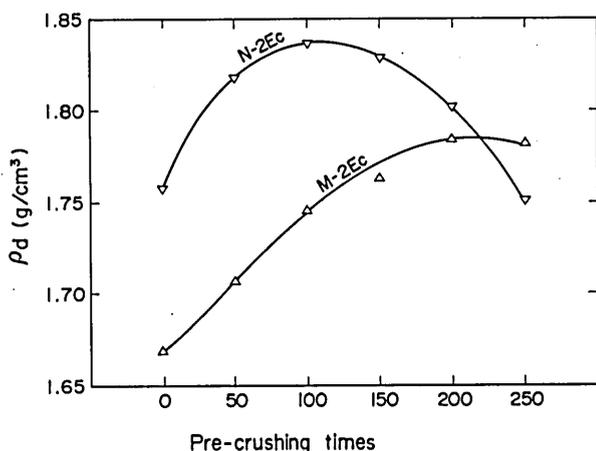
FIG. 15. Variation of ρ d with increasing compaction time.

B. CONSTITUENT MINERALS OF SOIL GRAINS

With the sifted specimens used for the grain size analysis, constituent minerals of soil grains compacted with 0 (natural state), 100 and 300 times, respectively were examined under the stereoscope. Since the alteration of constituent minerals except quartz, is considerably remarkable, the colourings of K-feldspar and plagioclase were carried out by the method of Eguchi et al. (1964). The results obtained are presented in Table 8. As is clear in the Table, with decreasing grain size quartz content decrease while altered plagioclase has a tendency to increase. The maximum quartz content is found at the 100 times compaction for specimen N, while in the M specinens it increases with increasing compaction times. The relationship between the compaction times and the quartz content closely correlated with the relation between the compaction times and the compaction dry density, suggesting an intimate relation between the compaction dry density and quartz content in soil grains. Concerning mineral shapes, it is of note that fractured quartz and potash-feldspar with angular surfaces increase with increasing compaction times. Individuality of minerals increases with increasing compaction times in the both specimens of M and N as indicated in Table 9. A similar tendency is shown as a function of grain size, i.e., the less the grain size, the more individuality. This tendency is independent of the mineral species in the range of larger grain size. However, in the finest grain size (less than 74 μm), amount of plagioclase and its alteration products should be quite significant.

TABLE. 8. GRAIN SIZE VARIATION AS A FUNCTION OF COMPACTION USING RAMMER.

Rammer No.	4.76~2.00mm						0.84~0.42mm						0.25~0.105mm					
	q	K	p	b	o	p'	q	K	p	b	o	p'	q	K	p	b	o	p'
M 0	50.9	42.5	1.5	2.9	0	2.2	26.7	41.7	3.5	11.4	0	16.7	11.5	18.0	0.9	11.3	0	58.3
M 100	53.4	24.6	1.0	1.7	0.4	18.9	31.7	33.1	2.9	12.8	0	19.3	27.2	25.0	0	9.4	0	38.4
M 300	62.6	25.9	0.4	1.4	0	9.7	34.4	43.6	1.0	3.6	0	17.4	25.0	28.0	2.2	0.4	0	44.4
N 0	53.2	16.8	0.9	6.6	0.4	22.1	30.0	30.4	1.6	13.6	0	24.4	43.8	29.0	0.4	7.4	0	19.4
N 100	62.2	20.0	0.4	5.2	0	12.2	47.8	17.4	0	10.4	0	24.4	60.4	9.2	0.2	6.4	0	23.8
N 300	52.0	25.2	0.6	6.0	0	16.2	43.0	31.6	0	12.8	0	12.6	37.2	21.8	0.2	13.6	0	27.2

(q : quartz, K: K-feldspar, p: plagioclase, b: biotite, o: other minerals, p': alteration plagioclase)

TABLE. 9. VARIATION OF SOIL GRAIN'S INDEPENDENCY AS A FUNCTION OF COMPACTION USING RAMMER (%).

Rammer No.	4.76~2.00mm						0.84~0.42mm						0.25~0.105mm					
	q	K	p	b	o	p'	q	K	p	b	o	p'	q	K	p	b	o	p'
M 0	0	0	0	0	0	0	0	3	2	0	2	0	2	1	0	0	0	0	13
M 100	0	0	0	0	0	0	5	0	1	2	0	2	8	2	0	1	0	3
M 300	3	0	0	0	0	0	6	1	0	0	0	0	9	9	1	0	0	19
N 0	2	0	0	0	0	0	2	4	0	0	0	1	15	9	0	3	0	6
N 100	4	0	0	0	0	0	7	1	0	1	0	4	26	2	0	3	0	9
N 300	7	0	0	0	0	1	10	5	0	1	0	2	15	7	0	5	0	10

C. CLAY MINERALS

Crushing effects on clay mineral constituent in Masa were examined with the sifted specimens after 0 (natural state), 100 and 300 times of compaction by means of the X-ray powder diffraction method. Silt fractions of 74 to 5 μm and clay fractions of less than 5 μm were subjected to examine the constituent of clay minerals as a function of crushing times. A fixed amount of pulverized specimens (100 mg) was kneaded and flattend on the glass plate. In order to examine the results quantitatively, X-ray conditions such as accelerating voltage were kept constant.

1. X-ray powder diffraction pattern of the silt fraction

The X-ray powder patterns for silt fractions (74 to 5 μm) of specimen M is shown in Fig. 16-a. As shown in this Figure, halloysite (7 Å) is predominant including a small amount of halloysite (10 Å). Atention must be paid to the fact that the ratio of the relative intensity between halloysite (7 Å) and halloysite (10 Å) does not

vary with increasing compaction times. On the other hand, in specimen N, only very little amount of halloysite is recognizable and vermiculite begin to appear as the compaction time increases (Fig. 16-b).

2. X-ray powder diffraction pattern of clay fraction

Fig. 17-a shows the X-ray powder pattern of clay
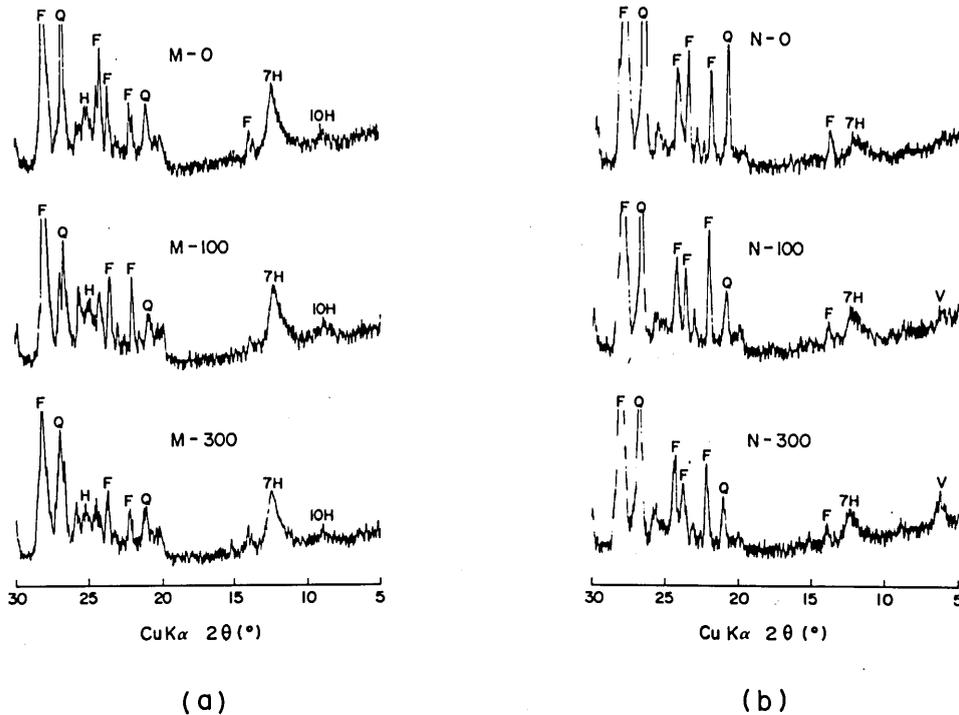

FIG. 16.   X-ray powder diffraction patterns of the silt with grain size between 74 and 5 μm.
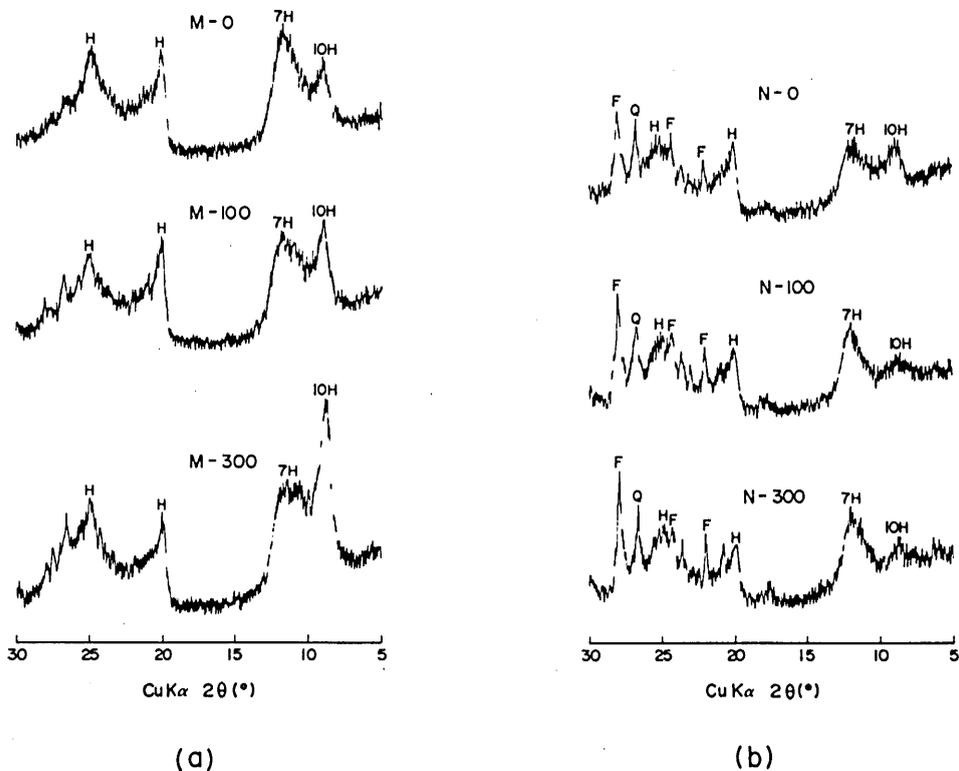(a): sample is from M location (b): sample is from N location

FIG. 17.   X-ray powder diffraction patterns of clayey constituent less than 5 μm.

fraction (less than 5 μm) of the specimen M as a function of the compaction time. As shown in this Figure, the constituent clay minerals are halloysite (7 Å) and halloysite (10 Å), the same as those of the silt fractions. The intensity of halloysite (10 Å) significantly increases with increasing compaction time. On the other hand, in specimen N, halloysite (10 Å) and halloysite (7 Å) both of which do not appear in silt fractions are predominant while vermiculite does not exist. Halloysite (10 Å) increases slightly with increasing the compaction time (Fig. 17-b). In relation to weathering process, rapid increase of halloysite (10 Å) at location M in the clay fractions of less than 5 μm, possibly represent the alteration characteristics of plagioclase. That is, the alteration process of plagioclase in granitic rocks has been established as follows; first, halloysite (10 Å) is formed, then it alters to kaolinite through halloysite (7 Å) (e.g., Kitagawa and Kakitani, 1977). The fact that halloysite (10 Å) crystals is probably finer than those of halloysite (7 Å) will help greatly to clarify the alteration process of plagioclase. Thus, it may be concluded that Masa at location M is in relatively earlier stage of weathering than those at location N.

VI. Discussion

"Masa" studied in this paper has been used as a core material of rock fill type dams. The safety of dam has been assessed from the view point of civil engineering. In this paper, the safety were examined based on the mineralogical studies as well as on the soil constants. Speciall attention was paid on the effects of compaction. In the following, some significant results obtained in the present research will be discussed in relation to the safety of a dam.

A. Compaction Properties as a Fanction of Pre-Crushings

As weathering proceeds, grain size of Masa becomes gradually finer and the void ratio increases by leaching (Matsuo and Nishida, 1970). At the same time, the maximum dry density (ρ dmax) becomes smaller and the optimum moisture content (Wopt) becomes greater, because the specific gravity decreases with increasing alteration of feldspars and biotite (Matsuo and Nishida, 1968). Considerable increase of the specific surface plays also an important role. The facts that ρ dmax increases and Wopt decreases with increasing pre-crushing time are probably caused because the fine soil grains produced by pre-crushing are quite resistive against the crushing. This is the exact opposit of natural weathering process. Soil grain is hardly crushable against pre-crushings which is confirmable by the microscopic observations. That is, with increasing the pre-crushing time, micro-fractures becomes gradually independent to the optical boundary of the constituent minerals (Table 7). Soil grains of Masa is crushed or dispersed mainly in the direction perpendicular to the compacted axis (Tables 4 and 5), and voids or relatively loose matrixes are developed in the interstices of the soil grains. However, pre-crushed soil grains are hardly crushable compared with those of natural stat even with a high compaction energy resulting

high dry density. Moreover, low value of Wopt as the result of pre-crushing can be interpreted as being caused by densification without mineral alteration. The improvement of imperviousness due to pre-crushings, as shown in Table 1, can be explained as the result of increased matrix and high densification.

One of the most important result of the present study is finding of over crushing phenomenon. The high density of the pre-crushed Masa is caused by the fact that the interstices of between quartz and/or K-feldspar are filled with clay minerals, i.e., matrix. However, if the grains of quartz and K-feldspar are overcrushed, voids or interstices surrounded by angular surface of these minerals increase considerably resulting the relative decrease of the matrix. This fact can be comparable with the gravel ratio theory developed by Walker and Holz (1951), though the grain size is fairly different. That is, volume of voids between the interstices of soil grains increase and as the result, interference between soil grains increase. The difference of the optimum time of pre-crushing between M and N may be caused by the difference of the weathering degree. This is also confirmed by the fact that M is relatively fresh and composed of coarse grains such as gravel and coarse sand fractions, and also M is hardly crushed. Thus the ratio between surfaces of quartz and K-feldspar and matrix keeps balanced with each other.

B. "Masa" as the Core Materials of Rock Fill Dam

The safety of dams greatly depends upon the quality of the core materials, especially on the imperviousness of the materials. Generally, fine grain materials including large volume of clay minerals, such as extensively weathered soil mudstone and tuffacicious rocks show high imperviousness. However, the natural moisture content of these materials are in general, quite higher than the optimum moisture content. Thus the practical construction process of a dam have forced to done in a state of high moisture content. Accordingly, the types of roller machines are limited and a sufficient degree of compaction can not be expected. However for Masa whose differences between natural moisture content and the optimum moisture content is small can be regulated to an appropriate moisture content. Grain size distribution of Masa also help the construction. Consequently, sufficient degree of compaction and imperviousness can be obtained through the process of pre-crushing. For recently built large size dam, sufficient strength of core materials is required against earthquakes. So, Masa whose high degree of compaction has a relatively greater of utility value. However, since the permeability coefficient of "Masa" increases rapidly in the range of less moisture content than the optimum moisture contennt, special careful control of moisture content is required during construction, and, particularly, effect of over crushing should be also considered. It should be noted that the void shapes show a random orientation against the compaction direction. This indicates the excellency of "Masa" as a core material because of its uniform permeability which will be very inportant to water permeation.

All of the investigated locations are close to the

respective dam, and correspond to low-relief surfaces such as Kibi plateau and Setouchi surface where weathered granite, Masa is well developed. Such topographical conditions are also important in securing a large volume of Masa for dam construction.

VII. CONCLUSION

Since "Masa" has various advantages such as well compaction by approprate controll of moisture content and high imperviousness as well as no peculiar orientations in its permeability. Therefore, large size fill dams have been constructed in Chugoku district where granitic rocks are widely developed. Since "Masa" also has the advantage that the imperviousness can be improved by pre-crushing process, relatively little weathered "Masa" can also be used as core materials. Accordingly, it is possible to secure the required volume of core materials even from the limited possible sampling areas. The quality of core materials has been judged by various values of civil engineering constants. The effect of the pre-crushings of "Masa" has been judged based on the experimental engineering basis, and the detailed constituent of "Masa" has not been examined especially from the view point of mineralogy. In this paper, quantitative effect of pre-crushing were examined from the mineralogical view point. Microscopic observation and examination by X-ray powder method reveal the important mineralogical characteristics of Masa in relation to the pre-crushing. Furthermore, effects of over crushing were quantitatively established. The results obtained should be of significance for the further safety in constructing fill dams.

References

AOYAMA, C., TOHYAMA, S. and NISHIDA, K. (1977): Soil structures of undisturbed Masa in relation to void ratio (abstract in Japanese). 12th. Civ. Eng. Conf., D-3, 149-152.

EGUCHI, M., SHOJI, R. and SUZUKI, S. (1964): Mineral frequency determinations of quartzose sands by stairing of feldspar (in Japanese with English abstract). Jour. Tohoku Min. Soc., 11, 71-78.

FUKUMOTO, T. (1972): Effect of particle breakage on compaction density of decomposed granite soils (in Japanese). Jour. Jap. Soc. Soil Mech. Found. Eng., 12, 55-63.

——— (1978): Permeability of weathered granite, Masa (in Japanese).Jour. Ritsumeikan Univ., No. 34, 65-77.

JUSTIN, J. D. and CREAGER, W. P. (1947): Engineering for dams. Vol. III, John Wiley & Sons.

KAIZUKA, S. (1950): Geomorphology of the western part of Chugoku (in Japanese with English abstract). Bull. Geogr. Inst. Tokyo Univ., No. 1,87-98.

KAKITANI, S. (1974): Weathering of granite and topography in Hiroshima Prefecture (in Japanese with English abstract). Geomorph. Sci. 21, 1-8.

——— (1975): Weathering and Slope failure of the studies on the prediction for natural disaster according to the development of the coastal zone, Seto Inland Sea (in Jnpanese). Sp. Rep. Nat. Disa., No. A-50-7, 13-20.

KANAORI, Y. and SAITO, K. (1979): Geologic investigation on the Matano pumped storage station (in Japanese). Cent. Res. Inst. Elect. Power Ind. Rept., No. 379505.

KASHIWAGI, H. (1963): Studies on the weathering of granite (Preliminary Report)(in Japanese with English abstract). Geol. Rep. Hiroshima Univ., 12, 319-342.

KITAGAWA, R. and KAKITANI. S. (1977): Alteration of plagioclase in granite during weathering. Jour. Sci. Hiroshima Univ. Ser. C, 7, 183-197.

KOHNO, T. (1984): Weathering and landforms of granitic area in the central part of Chugoku district, Southwest Japan (in Japanese with English abstract). Bull. Coll. Lib. Arts Kyushu Sangyo Univ. Sp. 20th Anniv. Soc. Found., 63-322.

MATSUO, S. and NISHIDA, K. (1966): Weathered granite (Masa) and its engineering soil constants (in Japanese). Rept. Kyoto, Ind. Train., No. 3, 63-68.

———, ——— (1968): Physical and chemical properties of the decomposed granite soil grains. Soils Found., 8, 10-20.

———, ——— (1970): The properties of decomposed granite soils and their influence on permeability. Soils Found., 10, 93-107.

——— and FUKUMOTO, T. (1976a): Factors affecting the crushability of decomposed granite soil (in Japanese). Jour. Jap. Soc. Soil Mech. Found. Eng., 16, 85-92.

———, ——— (1976b): Influence of particle breakage on the compaction characteristics of decomposed granite soil (in Japanese). Jour. Jap. Soc. Soil Mech. Found. Eng., 16, 93-102.

———, ——— (1977a): Relationship between the weathering and crushability of decomposed granite soils (in Japanese). Jour. Jap. Soc. Soil Mech. Found. Eng., 17, 99-106.

———, ——— (1977b): Significant drop in permeability due to particle breakage of decomposed granite soils (in Japanese). Jour. Jap.Soc. Soil Mech. Found. Eng., 17, 87-97.

OGATA, S., KAKUDA, T. and KIKUCHI, K. (1978): Geologic investigation on the Nabara pumped storage station (in Japanese). Cent. Res. Inst. Elect. Power Ind. Rept., No. 377028.

OKAMURA, Y. and NUREKI, K. (1962): The Ryoke metamorphic belt of the Yanai district (in Japanese). Guide-book, Geol. Excurs., Hiroshima Univ. (Dep. Geol. and Miner.).

PROCTOR, R. R. (1933): Four articles on design and construction of rolled-earth dams. Eng. News Rec., 3, 245-248.

——— (1933): Fundamental principles of soil compaction. Ibid, 3, 286-289.

——— (1933): Field and laboratory verification of soil suitability. Ibid, 3, 348-351.

——— (1933): New principles applied to actual dam-building. Ibid, 3, 372-376.

TAKAHASHI, S. and TANAKA, Y. (1984): On the weathering of constituent minerals in decomposed granite soil and the moisture characteristics (in Japanese). Ground Eng., 2, 13-22.

WALKER, F. C. and HOLTZ, W. G. (1951): Control of embankment material by laboratory testing. Proc. ASCE, No. 180.

YOSHIDA, H. (1962): Mesozoic igneous rocks in the vicinities of Hiroshima and Kure cities (in Japanese). Guide-book, Geol. Excurs., Hiroshima Univ. (Dep. Geol. and Miner.).

RYOGI ORIGUCHI

GEOLOGICAL SECTION, CHUDEN ENGINEERING CONSULTANTS CO. LTD., 2-3-30, DESHIO-CHO, MINAMI-KU, HIROSHIMA, 734, JAPAN.