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Quality control of high embankments constructed of soft sedimentary rock materials

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ABSTRACT: A quality control method was proposed in the present paper for the construction of high embankment consisting of soft sedimentary mudstone materials. Properties of particle breakage in the process of excavation, spreading and roller compaction and those of weathering and strength reduction of materials due to cyclic action of wetting and drying were fully investigated in the laboratory, in order to discuss appropriate zone arrangement in the embankment and to propose proper standard values for the quality control of the fill. Through these detailed discussions and severe construction control in the field, much higher quality of high embankment was satisfactorily attained in a project of land improvement.

1 INTRODUCTION

Soft sedimentary rocks such as mudstones of silt and clay, shale and slate, and tuffs have often been used for fill materials in both intact and weathered conditions. It has well been known that these soft rocks are likely to show slaking and weathering when they are released from in-situ high confining pressures by excavation and are exposed to an open-air stress free conditions. Slope failures and/or large settlement associated with the strength reduction and change in compressibility due to weathering have often been reported in earth fills constructed of such soft rock materials, so that much attention should be paid on the proper testing method of materials, appropriate zone arrangement, and minute quality control of the fill in different stages of excavation, crushing and placement of materials (Ohne 1984, Shima & Imagawa 1980).

A quality control method was proposed in this paper for the construction of high embankment consisting of soft sedimentary mudstone materials. Properties of particle breakage in the process of excavation, spreading and roller compaction and those of weathering and strength reduction of materials due to cyclic action of wetting and drying were fully investigated in the laboratory. In order to examine validity of the proposed design method, field studies including settlement measurements were also done for an actual embankment in a project of land improvement.

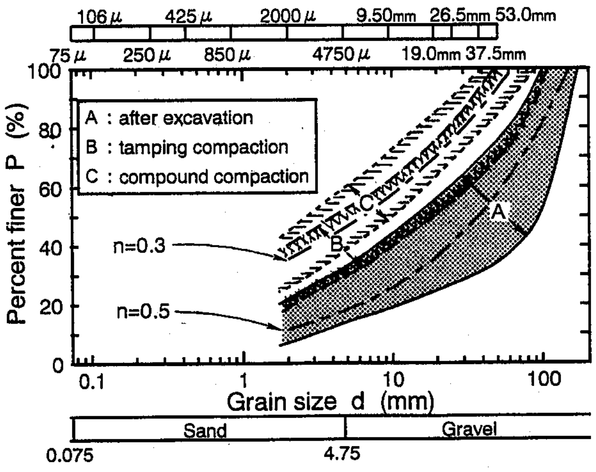
2 MATERIAL PROPERTIES OF SOFT ROCKS

2.1 *Particle breakage and grain size distribution*

Although soft rock materials show a marked change in gradation due to particle breakage in the process of construction, it is much convenient to express their grain size distribution by using the following Talbot equation

$$P = (d/D)^n \times 100\ (\%) \qquad (1)$$

where the maximum grain size (D) and the power number (n) are to be parameters of the equation for identifying a gradation curve.



.Figure 1. Particle Breakage of Soft Rocks

A representative result of particle breakage is shown in Figure 1 for a soft rock material, having unconfined compressive strength (q_u) of about 2 ~ 10MPa, in which gradation (A), (B) and (C) in turn corresponds to the state just after bulldozer spreading of materials following ripper excavation, that after compaction with a single tamping roller and that after compound compaction by using a few different rollers, respectively. Including similar field data obtained in other projects, characteristics of gradation change of soft rocks due to particle breakage are summarized as follows;

① Gradation curves generally show parallel shift, with the same n-value, due to particle breakage.

② The n-value after bulldozer spreading usually ranges in 0.3 ~ 0.6; poor gradation can be avoided by improving procedure of ripper excavation.

③ The n-value becomes equal to around 0.3 by an ordinary compaction, and reaches up to 0.2 in compound compaction. It is very hard to get a state of $n \leqq 0.2$ only with compacting efforts.

Incidentally, Marsal has defined a practically useful parameter of grain breakage (B_g), which expresses the change in gradation curves as a numerical value (Marsal 1973). This B_g-value can be related in an analytical form to the Talbot parameters (D,n) in Eq. (1) as follows; i.e., in case of gradation change from (D_1,n_1) to (D_2,n_2)

when $n_1 \neq n_2$ and $p < \zeta$

$$B_g = (1/\zeta^{q} - 1/\zeta^{q\zeta})\,p^{q} \tag{2}$$

when $n_1 = n_2$ or $p \geqq \zeta$

$$B_g = 1 - 1/p \tag{3}$$

where $\zeta = n_1/n_2$, $\eta = D_1/D_2$, $p = \eta^{n_1}$, $q = 1/(\zeta - 1)$. Both of the parameters (D,n) and B_g can be used effectively for a quality control of soft rock fills by relating them to such properties of slaking and strength reduction as described below.

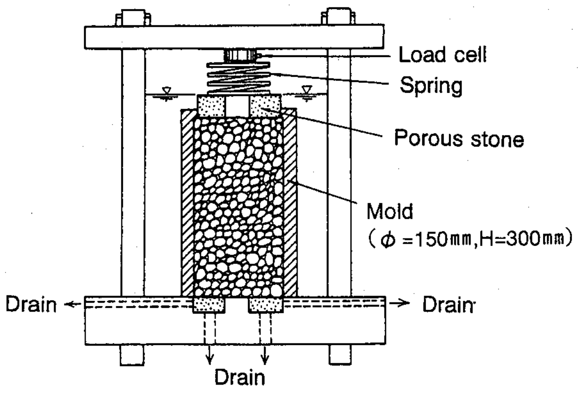


Figure 2. Test Apparatus for Weathering

2.2 *Strength reduction due to weathering*

Soft rock materials more or less show particle breakage and strength reduction due to weathering, which mostly depend on their initial gradation and field density as placed and the confining pressure acting on them in the fill. Laboratory tests were conducted for a soft rock material to investigate fundamental aspects of these influential factors for use in an actual embankment design.

The apparatus used in the test is illustrated in Figure 2, in which a cylindrical specimen of rock material first undergoes five cycles of wetting and drying weathering processes under a specified constant vertical pressure (p_v) in a similar way as adopted in the stabilization test for concrete aggregate. The specimen is then loaded vertically in a triaxial cell with a lateral confining pressure of 100 ~ 300kPa to obtain its shearing strength after weathering.

Material properties of the sample and testing conditions adopted are listed on Tables 1 and 2, respectively. In the latter, the degree of compaction (D_n) is defined here as a ratio of a compacted dry density (ρ_d) to the dry density of the intact rock particle (ρ_r), as follows

$$D_n = (\rho_d / \rho_r) \times 100\,(\%) \tag{4}$$

instead of the ratio to the maximum compacted dry density (ρ_{dmax}) usually used in the design. This is because of the fact that the value of ρ_{dmax} to be a standard of the degree of compaction itself changes much in soft rock materials, together with their grain size distribution, in various processes of embankment construction. According to the results of laboratory compaction tests on soft rocks so far presented, compacted states with the values of air content (v_a) less than 15% correspond to D_n-values of 80 ~ 85%, and for v_a less than 10% to D_n of 85 ~ 90%.

Test results are summarized in Figure 3, where strength reduction due to weathering is plotted on

Table 1. Material properties

Density of soil particle (ρ_s) :	2.63g/cm³
Dry density of soil particle (ρ_r) :	1.34g/cm³
Water absorption:	37.0%
Compressive strength (q_u) :	8.6 ~ 20.1MPa
Montmorillonite content:	9 ~ 14%

Table 2. Test conditions

Vertical load (p_v) :	50, 100kPa
Talbot n-value (n) :	0.4, 0.5, 0.6
Degree of compaction (D_n) :	85, 90%

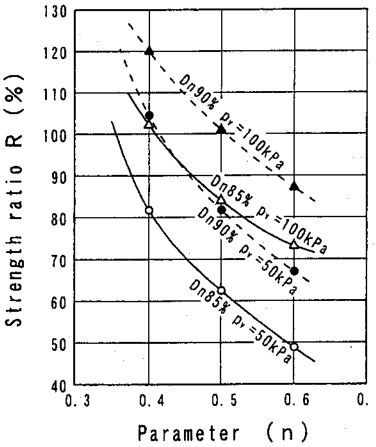


Figure 3. Strength Reduction due to Weathering

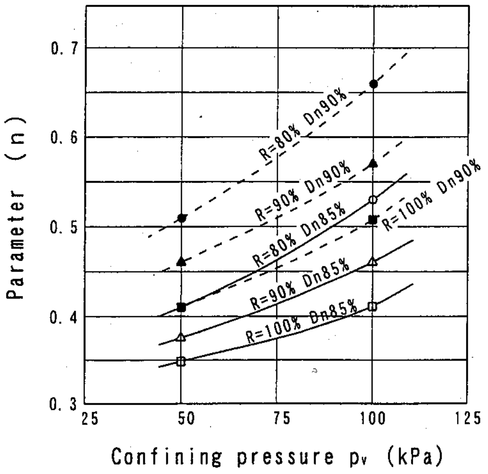


Figure 4. Determination of Design Values

the ordinate, for every combination of testing conditions, as a strength ratio R (%) of deviator stresses after to before weathering process. Points to be noticed in the figure are as follows;

① Strength reduction is restrained by increasing finer content (decreasing n-value), by compacting in higher density, and by increasing overburden vertical confining pressure.

② R-value can show an increase over 100% due to densification accompanied by particle breakage during weathering process.

③ Soft rock samples having almost the same value of water absorption as that of intact rock do not proceed severe slaking, showing a little strength reduction of R over 70%.

3 QUALITY CONTROL OF EMBANKMENT

Test results presented in Figure 3 are redrawn in Figure 4, as a relationship between (n) and (p_v), for representative values of R=80, 90, 100%. It is recognized that by using this figure the thickness of surface soil layer to be overlaid, which corresponds to the overburden pressure (p_v) required to ensure the design strength, can be determined for specified conditions of field grain gradation (n) and required degree of compaction (D_n) of fill materials. For instance, the value of (p_v) necessary to avoid strength reduction (R=100%) can be read to be about 95kPa for a case of n=0.5 and $D_n \geqq 90\%$, which is equivalent to the thickness of overburden soil layer of around 5m.

In the project of land improvement mentioned in this paper, zone arrangement of the embankment should have been done by taking a little strength reduction into account because the amount of soil material required for overburden load was quite limited, being only about half of requisite.

The standard cross-section of the embankment finally adopted in the design is illustrated in Figure 5. The main body of the fill (zone 2) consists of two sections according to the degree of compaction necessary to ensure individual design strength; i.e., a little strength reduction was allowed for in the determination of the standard values of the upper section. The standard values and quality control conditions thus determined are ① to keep $n \leqq 0.6$ for materials after excavation, and ② to compact

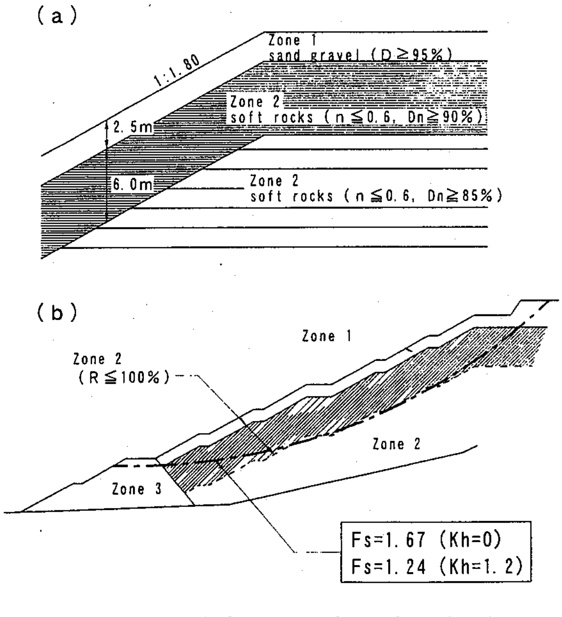


Figure 5. Standard Cross-section of Embankment
(a)Zoning (b)Stability Evaluation

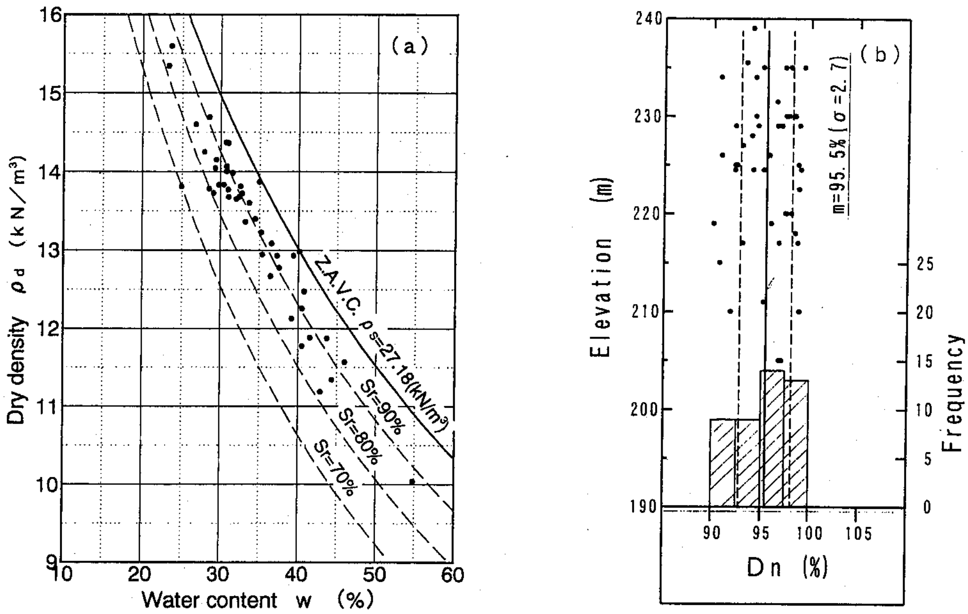


Figure 6. Quality Control Evaluation
(a)Scatter of Density (b)Distribution of D_n-values

sufficiently as $D_n \geqq 85\%$ and 90% corresponding to the sections in zone 2. In the former condition, ripper excavation is considered to be most effective for soft rock materials. An example evaluation of slope stability is presented in the figure, which demonstrates a satisfactory result giving sufficient safety against circular sliding of F_s over 1.50 for an ordinary state and over 1.20 for an earthquake of a seismic coefficient K_h=0.12.

The relationship between compacted dry density and water content measured on test samples taken in the field is plotted in Figure 6 (a), together with a frequency distribution of their D_n-values along with the elevation of placement in Figure 6 (b). It is clearly seen in the figure that the scatter of D_n -values can be controlled in a very narrow range though values of dry density themselves change much due to wide variations of the extent of weathering and grain gradation of fill materials. This suggests validity of the proposed method of density control of utilizing D_n-value, instead of usual definition of relative density, for soft rock materials.

Cross-arm measurements have revealed that the influence of seepage water by rainfall on the settlement after construction had been in practice negligibly small and the residual settlement anticipated to occur after providing for land use is presumed to be in the range 0.4 ~ 1.3cm, being less than 0.1% to the embankment height, which verifies sufficient compaction and satisfactory quality control during construction.

4 CONCLUSIONS

Concluding remarks drawn from the present study are summarized as follows.

1) For soft rock materials which show a marked change in gradation due to particle breakage in the process of construction, the Talbot equation can be used conveniently, together with the grain breakage (B_g), in expressing their grain size distribution.

2) Properties of particle breakage and strength reduction due to weathering of soft rock materials depend mostly on their initial gradation, compacted density and confining pressure acting in the fill.

3) A practically useful method of quality control is proposed for embankment construction of soft rock materials by using the degree of compaction (D_n) which is defined, instead of usual relative density, as a ratio of a compacted dry density to the dry density of the intact rock particle.

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