Applicability of Cement- Stabilized Mud Soil as Embankment Material

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Safety improvements

1. Outline

Along with the progress of measuring technologies in various fields and on the basis of the huge volume of accumulated data, design criteria have been improved to suit the situation in Japan where floods and earthquakes occur frequently. The current dam design criteria were formulated in accordance with the Government Ordinance for Structural Standard for River Administration Facilities, which was enacted in 1976. The number of dams with a height of over 15m completed in Japan more than 50 years ago exceeds 1,000. Most of these do not satisfy the current design criteria. Although no disastrous accidents such as dam failure have resulted from this, the safety of dams and the design flood discharge have been investigated and the necessary improvement works have been conducted in accordance with the latest design criteria.

2. Repair of earth dams

There are a number of older irrigation dams that were constructed more than 50 years ago. Among these, nearly 200,000 dams are small-scale earth dams (hereafter called "farm ponds") with a height of less than 15 m. In some urban areas, which have developed around farm ponds, an increasing volume of leakage threatens safety, demanding the immediate repair of nearly 20,000 farm ponds. In such areas, the following problems are likely to occur:

(1) It is difficult to obtain the embankment materials necessary to repair and reinforce the dam embankment , and the impervious material in particular, in the area around a farm pond,

(2) Although mud soil has accumulated in farm ponds and thus decreased the water storage capacity and caused water pollution, it is difficult to remove and dispose of the mud soil because of environmental concerns.

In order to solve these problems, a new improvement technique has been developed that utilizes mud soil in a farm pond as the embankment material. This method is called the "crushed and compacted embankment method," the mud soil is improved with a cement type additive to form stabilized soil, which is used as embankment soil to repair the embankment. This embankment soil made of stabilized soil is made by crushing cement-improved soil to a pre-determined maximum grain size, and then compacting it.

With the crushed and compacted embankment method, the stabilized soil which originally has the property of strain softening, behaves like a strain hardening material as a result of the crushing and compacting process and is resistant to cracking. So far, although cement-improved soil has a high strength, it breaks easily under small strain and so has not been used for constructing embankments as it would cause a difference of stiffness between the new embankment and old embankment.

Thus, as part of a government-industry joint project of the Ministry of Agriculture, Forestry, and Fisheries for research and development of new technologies entitled "Efficient improvement of earth dams", a method was developed to stabilized sediments in the bottom of the reservoir and use the product for repairing and strengthening earth dams (Figure 1). As shown in the flow chart in Figure.2, this method involves adding and mixing stabilization agents to sediments, curing the mixture for a certain period (ts*), breaking the hardened soil into grains of specified sizes using a breaking machine (Photograph 1), and immediately using the soil for embankment by roll compaction as ordinary banking materials. The method improves the deformation capacity of stabilized soil, which has low failure strain, by breaking and roll compacting the soil, and enables new embankment sections that have the same rigidity as the existing sections to be constructed.

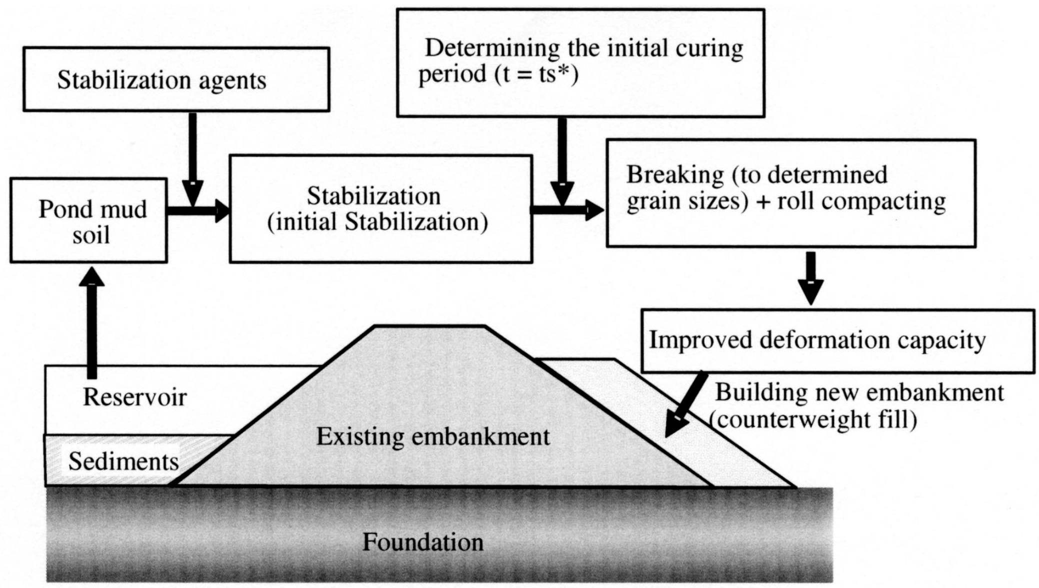

Figure 1 Use of stabilized sediments as banking materials

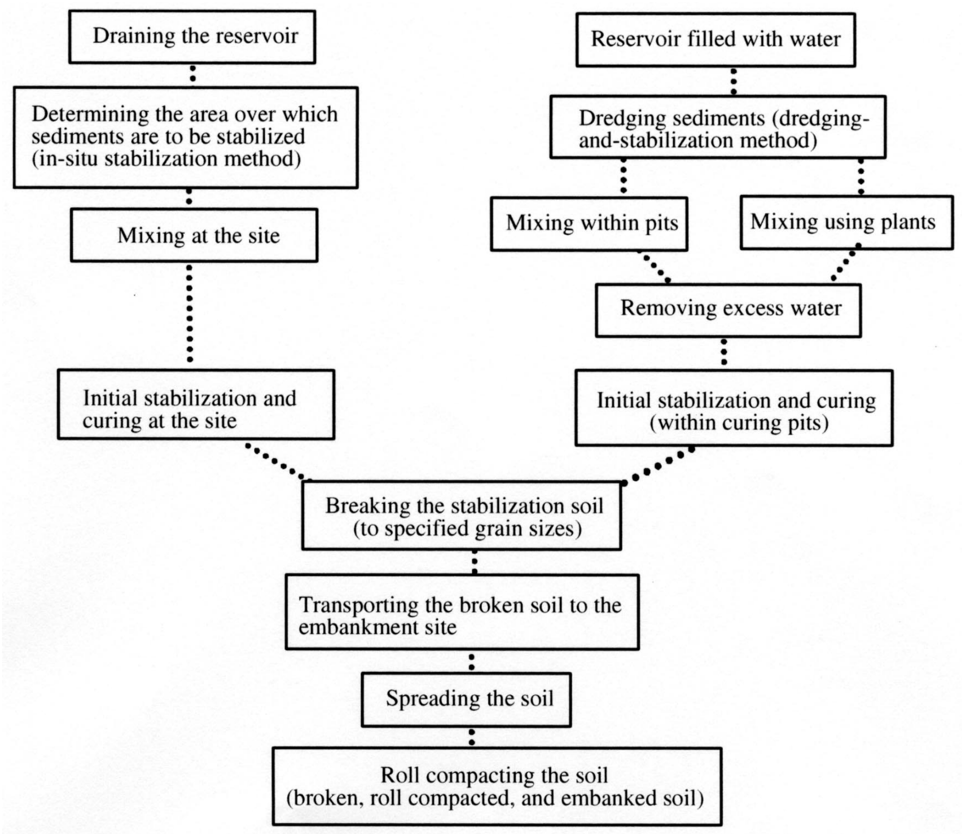

Figure 2 Process of the breaking and roll compacting banking method

The manifested strength depended on the days of curing (ts) and the grain sizes after breaking (Figure 4). Thus, banking materials having the required strength and deformation capacity equivalent to that of ordinary soil can be prepared by controlling the days of curing (ts) and grain size during breaking.Soil that has been stabilized, broken, and roll compacted using this method can be used for repairing and strengthening earth dams as 1) banking materials to widen the dams, 2) core materials, and 3) materials to raise the height of the existing earth dam to increase water storage capacity (Figure 5). The soil that has been prepared by mixing stabilization agents, curing for ts days to stabilized, breaking, roll compacting, and banking, showed larger failure strain than the initially stabilized soil and improved deformation capacity as shown by the stress-strain relationship derived by a triaxial compression test (Figure 3).

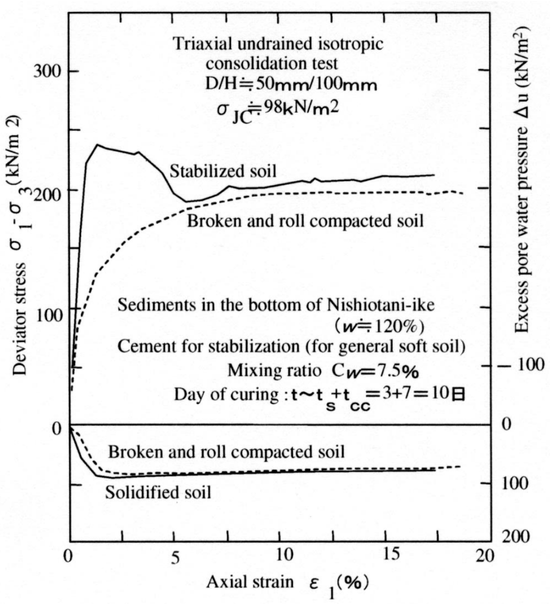

Fig. 3 Stress-strain curve

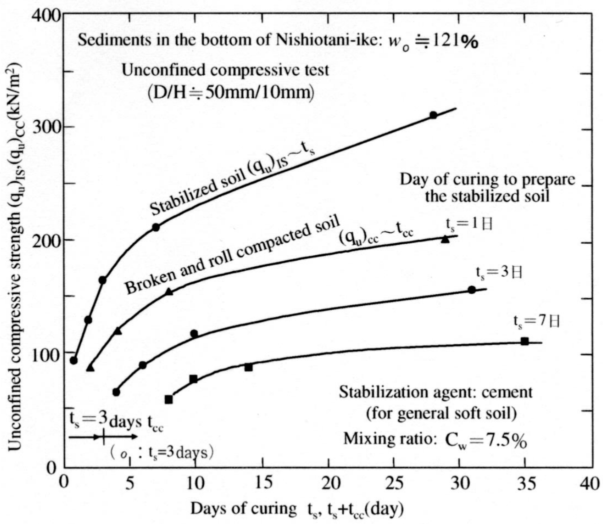

Fig. 4 Relationship between days of curing and unconfined compressive strength

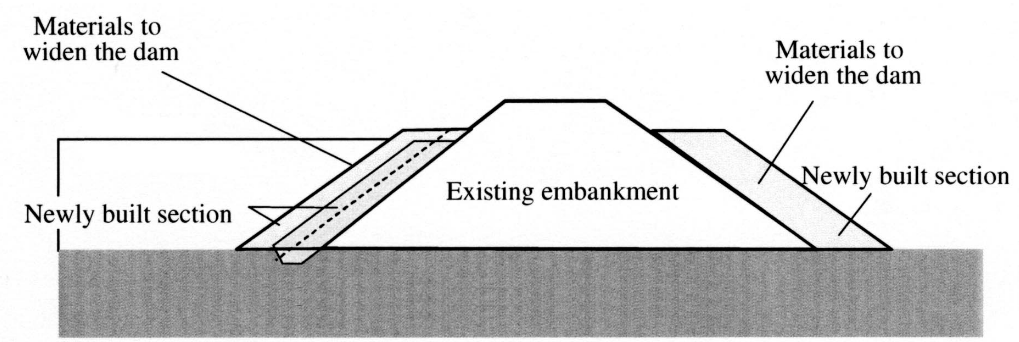

Fig. 5a Application of the breaking and roll compacting banking method (to widen a dam)

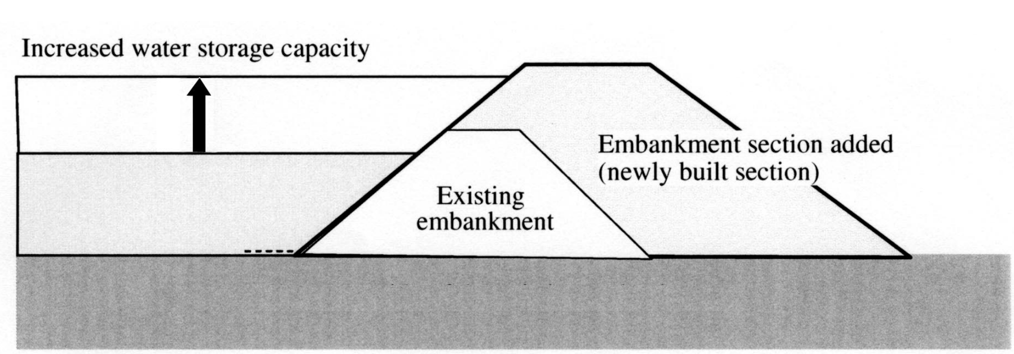

Fig. 5b Application of the breaking and roll compacting banking method (to raise a earth dam)

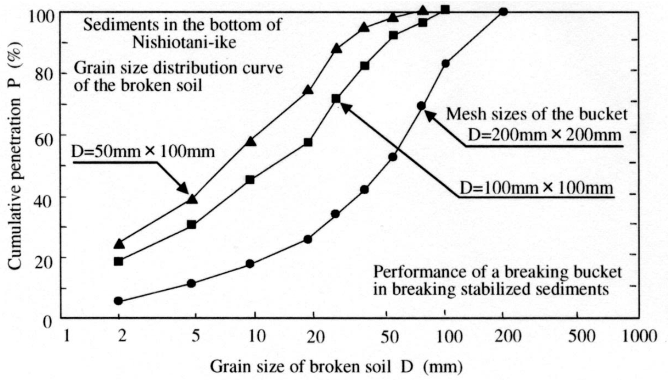

Fig. 6 Grain size of broken soil and grain size distribution

Photo 1 Breaking bucket

Some homogeneous earth dams that were designed and constructed at a time when the design criteria were not fully established cannot maintain stability against structural subsidence and liquefaction under earthquake conditions. Such structures need to be reinforced in accordance with current dam design criteria.

A typical method of reinforcing a dam embankment is to use counterweight fill. In an area where there has been an expansion of urbanization in the area around a dam and it is difficult to transport or utilize the required large volume of materials, the earthquake resistance of a dam can be enhanced with material extracted from a dam used as counterweight fill and the foundation soil reinforced. In this section, the situation of the Kitatani dam is introduced.

3. Repair work for the embankment of the Kitatani dam

The Kitatani dam in Mie Prefecture is formed by an old irrigation farmer's dam and its age is not known Figure 7 shows its location. Because of leakage from the slope toe and bottom trough as well as cross-sectional erosion of the embankment by aging, the Kitatani dam was evaluated as being unable to maintain stability during an earthquake. As a result, it was deemed necessary to construct a sloping core zone and completely repair the conduit and spillway in order to reinforce the dam embankment and prevent leakage. The specifications of the dam embankment before and after repairing are shown in Table 1.

The height of the Kitatani dam was 12 m and the slope was very steep. To ensure embankment stability and watertightness, the slope needed to be gentler

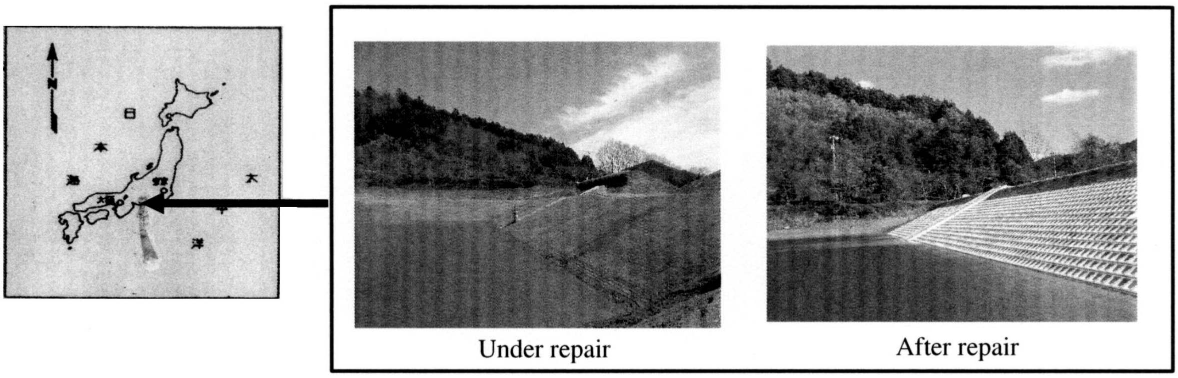

Figure 7 Location map

Table 1 Dimensions of the dam before and after renovation

Dimensions of the dam	Before repair	After repair
Dam type	Homogeneous type	Sloping impervious zone type
Dam height (m)	12.0	14.0
Crest length (m)	116.0	120.0
Dam volume (m^3)	25,500	36,000
Storage volume (m^3)	150,000	150,000
Volume of crushed and compacted soil (m^3)	—	16,000
Slope	1:1.6 (upstream average) 1:1.5 (downstream average)	1:2.1 (upstream average) 1:1.8 (downstream average)

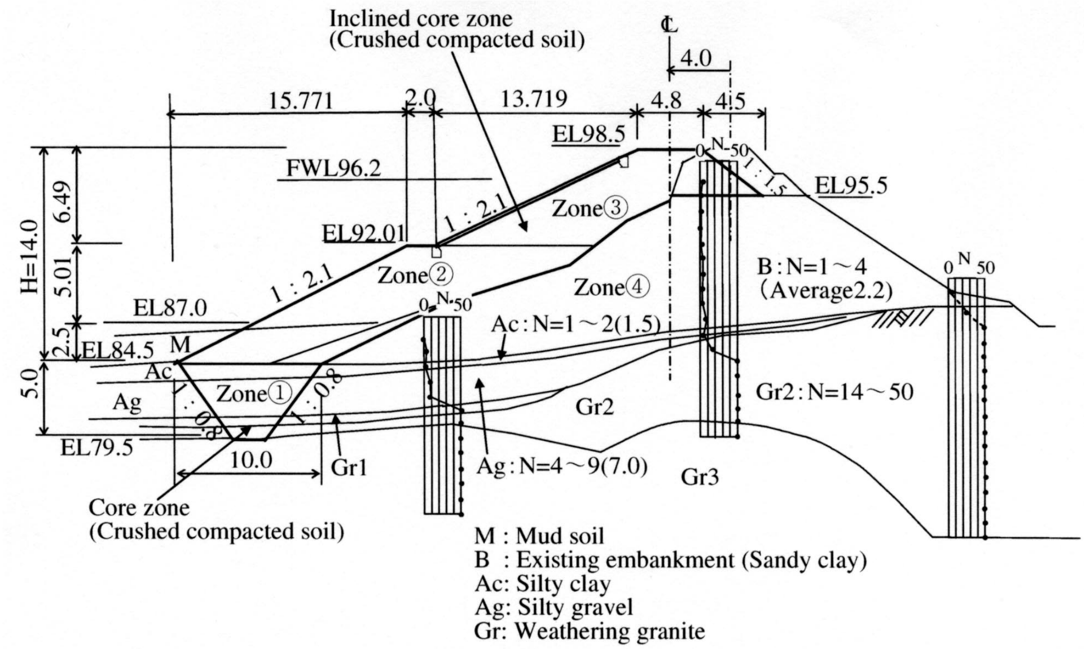

Figure 8 Typical cross-section of the dam

than about 1 in 3. However, an embankment with such a gentle slope would require a huge volume of embankment soil, which would likely severely reduce the storage capacity.

Consequently, the crushed and compacted embankment method was adopted in the Kitatani dam project. In repairing earth dams, the embankment soil requires strength to ensure the stability of the embankment and watertightness to store water. The merit of the crushed and compacted embankment method is that the embankment soil can be made artificially by controlling the cement content and the crushed grain size.

By adopting this embankment method, the following effects were observed in the Kitatani dam:

1) Because it was possible to prepare embankment soil having the pre-determined strength it was possible to repair the slope with a stepper gradient than would have been possible with ordinary materials as shown in the typical cross-section in Figure 8 thus reducing the volume of embankment materials needed and generating economic savings (the reduction of the slope from 1:3.0 to 1:2.1 reduced the quantity of material by over 40%).
2) Because all the embankment materials consisted of mud from the dam, there was no need to transport embankment soil in and out of the site and there was no reduction in water storage capacity, thereby avoiding damage to the environment, including the noise and exhaust emissions caused by dump trucks.

4. Conclusion remarks

Generally, in a farm pond with a dam height of 10 m or lower, the target strength of the crushed and compacted soil depends on the trafficability of construction machinery such as compaction rollers. However, in the Kitatani dam, the target strength was determined by that required for embankment stability since the embankment height was as high as 12m and the slope was as steep as 1 in 2.1. In most cases, there may be concern about the disparity in strength between the existing embankment and the inclined core zone newly constructed by the crushed and compacted soil, and this might lead to an undesirable consequence in the close contact of the two embankment zones. Accordingly, in the Kitatani dam, in order to reduce the effect of the disparity in strength between the existing and new embankments, the specifications of the required strength were altered in the top and bottom layers of the sloping core zone.

In order to reduce this disparity, the strength was determined to ensure the trafficability of construction machinery at the upper layer above the berm that is subjected to a larger seismic deformation, and at the layer below the berm where both the seismic deformation and the effect of disparity in strength are insignificant, and the strength was determined by the embankment stability. The quality of the crushed and compacted materials was controlled to investigate directly the strength rather than density in the ordinary soil embankment method, and tests were carried out on the embankment soil at volume intervals of about 1,500 m^3.