

CONSTRUCTION OF EARTH FILL STRUCTURE FOR SMALL FARM POND BY USING BHUTANESE TRADITIONAL WALL MAKING METHOD

* UENO Kazuhiro ¹, NATSUKA Isamu ², SATO Shushi ³, ONJO Norio ⁴, Karma Tshethar ⁵
and Kelzang Tenzin ⁵

¹ Academic Assembly, Shimane University, Japan;

² Emeritus Professor in Shimane University, Shimane University, Japan;

³ Natural Science Cluster, Kochi University, Japan;

⁴ Agricultural Development Consultants Association, Japan;

⁵ Department of Agriculture, Ministry of Agriculture and Forests, The Kingdom of Bhutan

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ABSTRACT: The Kingdom of Bhutan has mountains as high as 7,000 meters height at the east end of the Himalayas and the semitropical region at an altitude of 100 meters in its south area. Because of its precipitous terrain, stable supply of water for irrigation is difficult without efficient water supply system such as reservoirs, pipelines and so on. Based on the results of preliminary field investigations, existing reservoirs in the Kingdom of Bhutan often have structural problems in its body and foundation. To contribute to an increase in agricultural production in the Kingdom of Bhutan through the development of construction techniques for reservoirs, an earth fill structure for small farm pond was suggested and constructed in 2015. In this construction, Rammed earth method, which is well known as Bhutanese traditional wall making method, was applied as a compaction technique of soil. Authors conducted a follow-up of the earth fill structure in September 2017 to confirm the performance of the wall making method as a construction technique for reservoirs. Based on the results of the portable dynamic cone penetration tests, it is supposed that this rammed earth method couldn't achieve sufficient compaction energy for construction of earth fill structures for reservoirs because observed *N* values were comparatively small compared with that obtained from embankments constructed by modern compaction techniques. Therefore, in the construction of earth fill structures for farm pond by utilizing the rammed earth method, improvement in compaction technique should be considered.

Keywords: *The Kingdom of Bhutan; Wall making method; Earth fill structure; Small-scale reservoir; The portable dynamic cone penetration test*

1. INTRODUCTION

Although agriculture is a key industry in the Kingdom of Bhutan (hereafter call KB) [1] (agriculture constitutes 30 – 40 % of GDP), it has problems in an improvement of agricultural productivity. KB has mountains as high as 7,000 meters height at the east end of the Himalayas and the semitropical region at an altitude of 100 meters in its south area. Because of its precipitous terrain, stable supply of water for irrigation is difficult without proper management of water resource and reservoirs for storing irrigation water. Based on the results of preliminary field investigations, existing reservoirs in KB often have structural problems in its body and foundation. A water management system and construction techniques for reservoirs which can be applied to KB should be developed.

To contribute to an increase in agricultural production in KB through development of construction techniques for reservoirs, an earth fill structure for small farm pond was constructed by

Bhutanese people with advice from one of co-author in 2015 [2]. In this construction, Bhutanese traditional wall making method was applied as a compaction technique of soil to enable the sustainable construction and maintenance of reservoirs in KB. The wall making method is a traditional technique to make walls by compacting cohesive soil in formwork and is used in the construction of houses in KB [3]. Authors conducted a follow-up of the earth fill structure in September 2017 to confirm the performance of the wall making method as a construction technique for reservoirs.

In this paper, a concept and a construction procedure of the earth fill structure for small farm pond constructed in KB are described. Then, results of the follow-up of the earth fill structure are also reported.

2. EARTH FILL STRUCTURE FOR SMALL FARM POND CONSTRUCTED IN THE KINGDOM OF BHUTAN

Recently, large-scale reservoirs for electric power generation have been constructed in KB [4]. However, construction techniques for dam bodies of KB are not sufficient yet because most of those reservoirs were constructed with technical support from foreign engineers. In the preliminary field investigation conducted in 2014 and 2015, existing reservoirs constructed by KB own techniques often have structural problems in its body and foundation. Typical problem observed in the investigations was leakage of storage of water through foundation, abutment and boundary between dam body and foundation. Especially, poor treatment of the boundary seemed the main cause of leakage of storage of water because, for those reservoirs, sealing work have not been applied to the boundary between dam body and foundation. Improvement in design and construction techniques for reservoirs is required to ensure a stable supply of water and to increase agricultural production.

2.1 Concept of the Small-Scale Reservoir

In the northern and central parts of KB, agricultural lands are mostly in the form of stepped terrain because of precipitous terrain in those regions [5]. To enable a stable supply of water to such agricultural lands, small-scale reservoirs to be constructed by farmers themselves would be one of the effective solutions against water shortage. If farmers have construction techniques even for small-scale reservoirs, development of water resource for irrigation according to their water demand become possible by farmers own effort. Moreover, even if reservoirs are damaged due to natural disaster and their function is degraded with age, farmers can repair and maintain reservoirs by themselves. For this concept, construction of a reservoir with techniques which can be handled easily by farmers was planned. In this plan, the application of Bhutanese traditional techniques for making a stone wall and soil wall was attempted.

As mentioned above, a majority of agricultural lands in KB have a form of stepped terrain. When Bhutanese people develop agricultural lands on precipitous terrain, stone masonry is made for stabilizing walls existing between each stepped agricultural land. So, the stone masonry work has been familiar to Bhutanese people as a technique for stabilization of wall and slope. On the other hand, Bhutanese people build their houses by using the wall making method (Fig.1). The wall making method is a traditional technique for making walls by compacting cohesive soil in formworks. Most important things required to reservoirs, which body is made from earth materials, for continuing storage of water are stability as well as impermeability of earth fill structure. To ensure those functions of

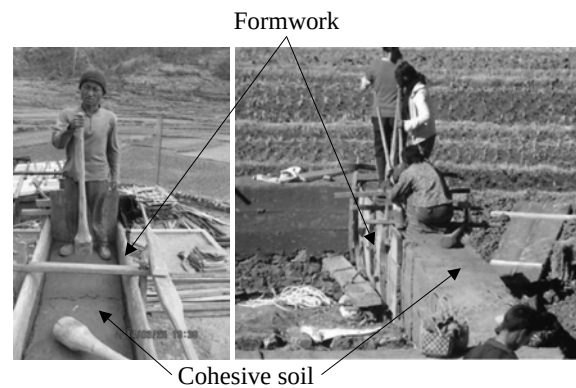


Fig.1 The wall making method

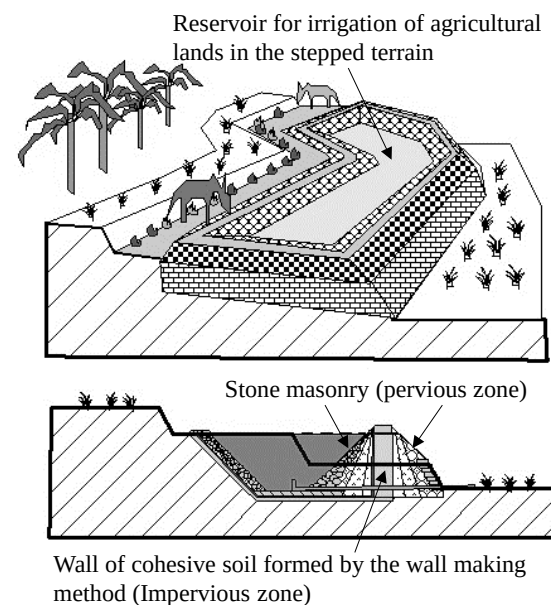


Fig.2 Schematic diagram of the small-scale reservoir with the concept in which Bhutanese traditional techniques is actively utilized

earth fill structures, in the construction of reservoirs with a modern design concept, bodies of the reservoir have often been designed with a couple of zones of earth materials [6] which have high strength (for pervious zone) or low permeability (for impervious zone). In the construction of such zoned bodies of the reservoir, the stone masonry work seemed applicable to the construction of pervious zone because stone masonry has a stable structure. On the other hand, the permeability of the wall of cohesive soil formed by the wall making method would be small, so this technique may be applied to the construction of impervious zone. The design and construction techniques for small-scale reservoirs in which Bhutanese traditional techniques are actively utilized should be developed for sustainable agricultural production in KB. Fig.2 shows the schematic diagram of the reservoir for



Fig.3 Location of Gebekha village

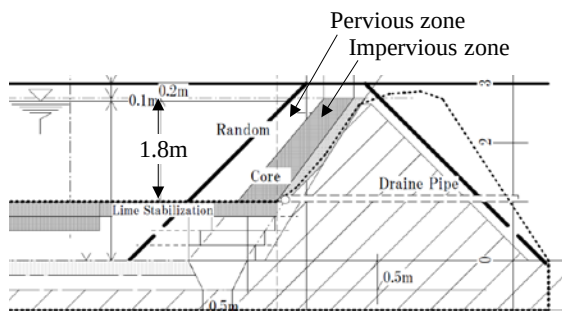


Fig.4 Cross section of the small farm pond originally planned

irrigation of agricultural lands in the stepped terrain with the concept mentioned above.

2.2 Construction Procedure of the Earth Fill Structure for Small Farm Pond

Construction of the earth fill structure for small farm pond was started with support of Japanese NGO in Gebekha village (Fig.3) in 2015. Cross section of the small farm pond in original plan is shown in Fig.4. Originally, cross section of the small farm pond was planned as a sloping core type dam. A time line of the construction is outlined below.

- 1) The construction was started on October 26 and it continued until October 30 with advice from co-authors.
- 2) After October 30, the construction was suspended until mid-November because farmers had to harvest agricultural product.
- 3) After harvest, farmers restarted the construction by themselves. Although co-authors left advice about construction techniques and procedure, farmers didn't obey those advice. As a result, as described latter, the small farm pond completed quite differ from that originally planned. Unfortunately, we don't know how the earth fill structure was constructed after the restart until completion.
- 4) The ceremony for the completion of the small farm pond was held on December 19.
- 5) Follow-up of the small farm pond was



Fig.5 Stabilization treatment of foundation by cement-mixed soil

conducted in 2017. The result of this follow-up will be described in the next section.

On October 26, construction of the earth fill structure for small farm pond was started with farmers in Gebekha village and co-authors. Detailed construction procedures are described below.

1) Stabilization treatment of foundation

Firstly, stabilization treatment of the foundation was conducted. Machinery excavation of original ground up to 1.5m depth was initially planned to obtain a more stable foundation. However, this plan was changed to manual excavation up to 25 – 50 cm depth because excavation machine couldn't be prepared. After removing unsuitable things for the foundation of reservoirs such as plant fragments from excavated soil, the foundation was reconstructed by tamping cement-mixed soil which was obtained by mixing the excavated soil and cement because enough bearing capacity of foundation couldn't be achieved by only tamping the excavated soil. The mixing ratio of cement was around 6 %. Fig.5 shows stabilization treatment of foundation by cement-mixed soil.

2) Construction of impervious zone

Earth material used for impervious zone was gathered from abandoned paddies and fields near from construction site. After removing large size gravel, the water content of earth material was adjusted by sprinkling water from a mountain stream. Although natural and optimum water contents [7] couldn't be measured, the water content of earth material suitable for compaction was decided according to its texture. In the compaction of impervious zone, the wall making method was utilized (Fig.6). The thickness of each layer of earth material was controlled so as to be about 8 cm after compaction. Every completion of compaction of three layers, permeability of compacted layer was measured by in-situ

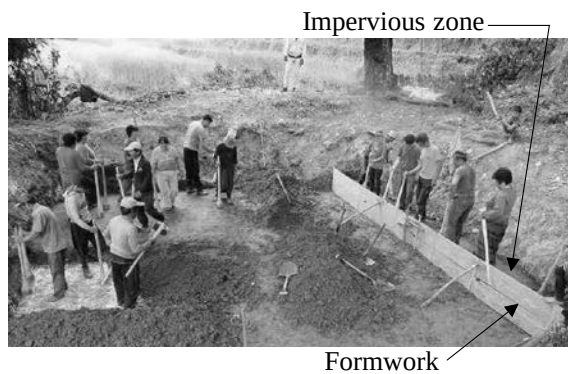


Fig.6 Compaction of impervious zone by the wall making method

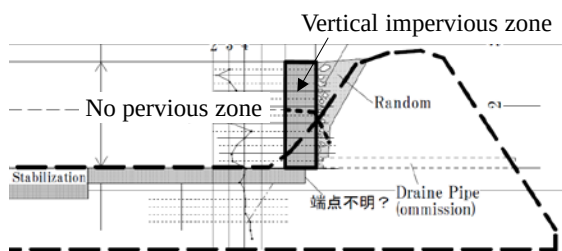


Fig.7 Cross section of the small farm pond completed

permeability test. After confirming hydraulic conductivity of the compacted layer was lower than 1×10^{-5} cm/sec, compaction of upper layers was started. Dry density of compacted layers was not measured.

3) Completion of the earth fill structure for small farm pond

After harvest of agricultural products, farmers restarted the construction of the earth fill structure for small farm pond by themselves. Co-authors left advice about construction techniques and procedure according to the original plan. However, farmers didn't completely obey those advice. They changed cross-section of the small farm pond. Cross section of the small farm pond completed is shown in Fig.7. The small farm pond completed quite differ from that originally planned. Firstly, although cross-section of the small farm pond was planned as a sloping core type dam as shown in Fig.4, that was changed to a vertical core type dam. Secondly, there was no pervious zone which should exist in front of impervious zone. Pervious zone is very important to increase the resistance of the body of reservoir against external forces and to protect the impervious zone from erosion. However, impervious zone of the small farm pond completed has been exposed to impounded water and rain. Reasons, why farmers changed cross section of the small farm pond, were that they

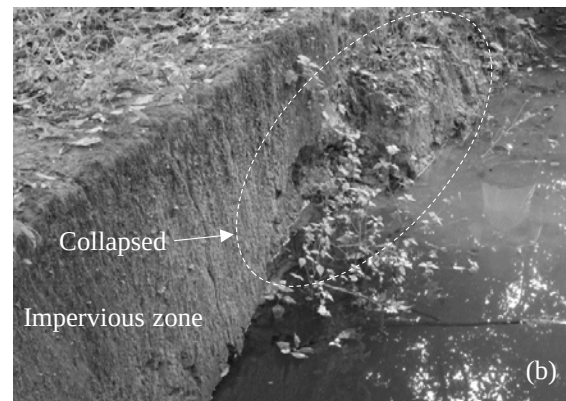


Fig.8 Condition of the earth fill structure at the follow-up

didn't want to reduce a reservoir capacity and that they couldn't understand the importance of pervious zone. For developing water resource steadily by farmers themselves, it is crucial to obtain a better understanding of farmers about design concepts of reservoirs.

3. FOLLOW-UP OF THE EARTH FILL STRUCTURE FOR SMALL FARM POND

Authors conducted a follow-up of the earth fill structure for a small farm pond in September 2017 to confirm the current condition of the small farm pond and to evaluate the performance of the wall making method as a construction technique for reservoirs. External observation and the portable dynamic cone penetration tests [8] were performed. Fig.8 (a) and (b) shows the condition of the small farm pond at the time of the investigation. Water was stored up to half of full capacity. Impervious zone had been collapsed partly because it was formed into the shape of the vertical wall and was not protected from impounded water and rain by pervious zone (Fig.8 (b)).

The portable dynamic cone penetration tests (JGS 1433) were conducted at impervious zone of the small farm pond which was constructed by utilizing Bhutanese traditional wall making method

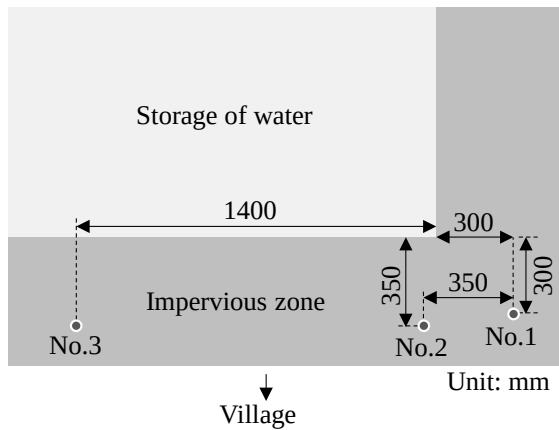


Fig.9 Testing points of the portable dynamic cone penetration test

in 2015 (Fig.6). This tests were performed at three points. The testing points are shown in Fig.9. In this tests, a cone with a diameter of 25 mm was driven into impervious zone in steps of 100mm by blows from a slide hammer with a mass of 5 kg falling through a distance of 500 mm. The numbers of blows required for this penetration were recorded as the penetration resistance N_d . Test results N_d were converted into N value which obtained by the standard penetration test (SPT), by employing Eq.(1) [9].

$$N_d > 4$$

$$N = 0.7 + 0.34 N_d \text{ (Coarse-grained material)}$$

$$N = 1.1 + 0.30 N_d \text{ (Sand)}$$

$$N = 1.7 + 0.34 N_d \text{ (Cohesive soil)}$$

$$(1)$$

$$N_d \leq 4$$

$$N = 0.50 N_d \text{ (Coarse-grained material)}$$

$$N = 0.66 N_d \text{ (Sand)}$$

$$N = 0.75 N_d \text{ (Cohesive soil)}$$

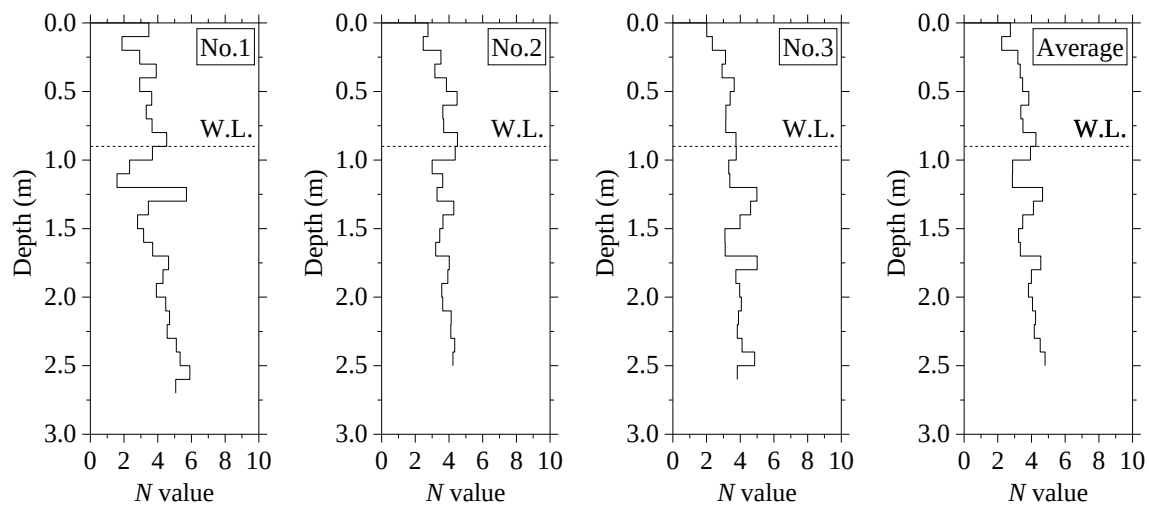


Fig. 10 Relationships between N value and depth

where N_d is the number of blows required for the penetration of 100mm and N is N value obtained by SPT. In this investigation, the equations for cohesive soil were employed.

Relationships between N value and depth are shown in Fig.10. With an increase in depth, N values increase gradually. Variation of N values between each testing point was comparatively large for No.1, while it was not so large for No.2 and No.3. The difference in a variation of N value might have been resulted by the difference in compaction conditions because No.1 was on a corner of the impervious zone. In the corner of the impervious zone, around No.1, compaction energy might have been biased due to a restriction of working space. Almost N values are plotted in a range of 3 to 5. Based on the results of the portable dynamic cone penetration tests, it is supposed that the wall making method couldn't achieve sufficient compaction energy for compaction of bodies of the reservoir because observed N values were comparatively small compared with that obtained from embankments constructed by modern compaction techniques. Therefore, in the construction of bodies of the reservoir by utilizing Bhutanese traditional wall making method, improvement in compaction technique should be considered according to conditions of bodies of the reservoir to be constructed and its foundations.

Possible measures for improving compaction technique utilizing Bhutanese traditional wall making method are listed below:

1) Increase in compaction energy

According to the test standard of JIS A 1210 [7], compaction energy is calculated by Eq.(2).

$$E_c = \frac{W_R \cdot H_R \cdot N_B \cdot N_L}{V} = \frac{W_R \cdot H_R \cdot N_B}{H_L} \quad (2)$$

where E_c is compaction energy, W_R is the weight of rammer, H_R is fall height of rammer, N_B is the number of blows by rammer, N_L is the number of layer of earth material, V is the volume of mold and H_L is the height of the layer of earth material. Increase in W_R , H_R , and N_B and decrease in H_L are effective to increase in compaction energy and to stabilize reservoirs to be constructed. Compaction energy which can be achieved by Bhutanese traditional wall making method and its effect on improvement in properties of compacted soil should be revealed.

2) Use of proper material

It is well known that the dry density of soil compacted under prescribed compaction energy is strongly affected by the water content of soil [10]. It is important to determine the compaction curve of earth material to be used in the construction of reservoirs and to adjust the water content of the earth material to around optimum water content.

3) Zoning of the body of the reservoir

In modern design concept, bodies of the reservoir have often been designed with a couple of zones of earth materials which have high strength (for pervious zone) or low permeability (for impervious zone). Pervious zone is effective to compensate for the low strength of impervious zone constructed by Bhutanese traditional wall making method. The stone masonry work which is one of the Bhutanese traditional techniques seems applicable to the construction of pervious zone because stone masonry has a stable structure. The design concept for reservoirs in which Bhutanese traditional techniques are actively utilized should be developed.

4. CONCLUSIONS

Development of construction techniques for reservoirs which can be handled by farmers themselves as well as the development of large-scale reservoirs with modern construction techniques would be an effective solution to contribute to an increase in agricultural production in KB. For this concept, an earth fill structure for small farm pond was constructed by farmers by utilizing Bhutanese traditional wall making method in 2015. However, the small farm pond completed quite differ from that of originally planned by co-authors because farmers couldn't understand the importance of design concepts for reservoirs. In the follow-up of the small farm pond conducted in 2017, it was confirmed that impervious zone which was formed into the shape of the vertical wall and was not protected from impounded water and rain by pervious zone had been collapsed partly. Moreover, Based on the result of the portable dynamic cone penetration tests, it is supposed that the

wall making method couldn't achieve sufficient compaction energy for compaction of bodies of the reservoir. Improvements in construction techniques utilizing Bhutanese traditional techniques and transfer of design concepts and construction techniques for reservoirs are needed to contribute to an increase in agricultural production through a stable supply of water for irrigation in KB.

5. ACKNOWLEDGMENTS

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