A Method of Construction of Small Ponds in Northeast Thailand

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Abstract

We described a construction method for small ponds or dams based on the results of mechanical tests performed on typical soils distributed in Northeast Thailand. As a result of the investigations of the performance of small ponds in relation to erosion and collapse, we proposed a simplified method of determination of the occurrence of collapse as well as methods of prevention of collapse. We also tried to estimate roughly the amount of settlement associated with the collapse. In terms of erosion, the slopes of the proposed pond were found to be stable.

Additional key words: collapse due to wetting, erosion, small pond, unsaturated soil

Introduction

In Northeast Thailand, the main irrigation facilities consist of small ponds. The ponds are isolated and there is no network between the ponds and no connection to the large-scale irrigation facilities. In future, these networks and connections might be important from the viewpoint of effective water supply[5]. Now, the ponds are mainly built by digging the ground. Most of these ponds however do not function well due to salinization of reservoir water, collapse and erosion of the slopes of the ponds. To obtain the basic information for overcoming these shortcomings, we have already described and discussed the mechanical properties of typical soils distributed in Northeast Thailand on or with which small ponds are constructed[4].

In this paper, we will propose and analyze a method of construction of small ponds or dams.

Development of a method of construction for small ponds or dams

The Department of Land Development (DLD) in Thai Government recommends a standard type for small ponds as shown in Fig. 1[2]. The pond has the following dimensions: 34 m length, 20 m width and 3.5 m height with 1:2 slopes. The capacity of the pond is about 1280 m^3. This pond belongs to the digging type. In this section, we will describe one type of small pond that is suitable for Northeast Thailand based on DLD's standard type small pond. As most of the area is covered with sandy or silty soils in Northeast Thailand, the technical problems are restricted to erosion and collapse[4]. We will analyze the performance of the type of small pond proposed in relation to erosion and collapse.

1) Type of small pond proposed

The standard cross-section of small pond proposed here is shown in Fig. 2. The kinds of soils considered as fill materials and foundations are sandy or silty soils. The dimensions of the small pond are as follows: 50~100 m length, 20 m width and 3 m height with 1:2 and 1:2.5 slopes. The pond is constructed by excavation and banking. The height of the embankment is 1 m, and the depth of the ditch is 2 m. The embankment is constructed by compacting the excavated soil. This type of pond shows the following characteristics.

(1) Since excavated soil is used as fill material, a yard for the disposal of the excavated soil is not necessary.
(2) If the proposed pond could be constructed in many areas, the groups of ponds may in future be used as water supply channels by connecting the ponds with each other.
(3) Since an embankment is included, structure is stronger than that of ponds made by only digging.
(4) Due to the shallow excavation depth, the pond is not readily affected by ground water.
(5) As salinization is unlikely on the embankment, the embankment is suitable for cultivation of field crops[5].

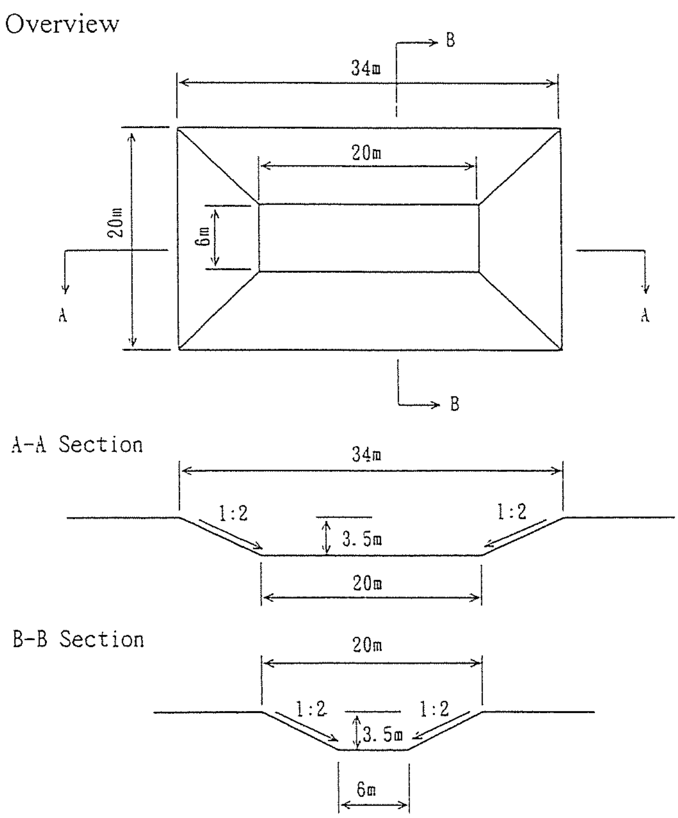

Fig. 1. Standard small farm pond recommended by DLD[2]

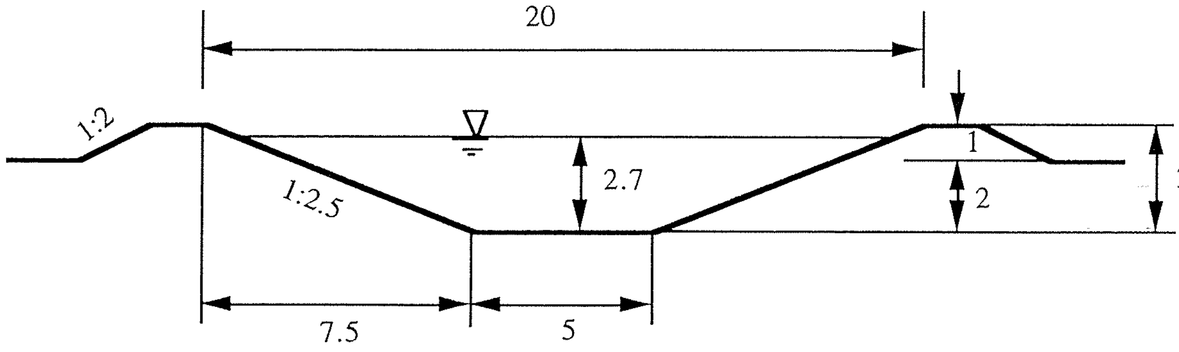

Fig. 2. Standard cross-section of proposed small pond

2) Resistance to collapse due to wetting

The e - log σ'_v lines obtained from oedometer tests for typical sandy and silty soils distributed in Northeast Thailand are shown in Figs. 3[8] and 4[4], where e is the void ratio and σ'_v the vertical stress. Though these soils are collapsible, settlement due to collapse depends on the initial water content and initial void ratio. Then it is necessary to measure the initial water content and initial void ratio before construction. If the initial void ratio is obtained, the possibility of collapse can be estimated as follows. If the initial vertical stress from wet density and overburden is estimated, the data of initial void ratio and initial vertical stress can be plotted in Fig. 3 or Fig. 4. If the plotted point lies on the left side of the saturated e - log σ'_v line, collapse does not occur, while if it lies on the right side, collapse may occur.

The possibility of collapse is schematically depicted in Fig. 5. The figure shows the volume change behavior due to the decrease in suction. If the stress point of the unsaturated soil is located on the right side of the normal consolidation line, collapse due to wetting can occur. A large volume reduction can be seen in the soil (points A→A' in Fig. 5), whereas if the stress point is present on the left side of the normal consolidation line, the soil can swell (points B→B' in Fig. 5). The process from points B→B' can be represented by the process from points C→C' in terms of effective stresses. As points C and C' lie on a rebound line in terms of effective stresses, the amount of swelling depends only on the reduction of effective stresses. Then, we can exactly calculate the amount of swelling if we estimate the reduction of effective stresses. Thus, unsaturated soils have generally a different behavior on the left and right sides of the normal consolidation line.

In the case of one-dimensional collapse, the amount of settlement due to collapse may be calculated as follows. The stress point after completion of soaking of water lies always on the saturated e - log σ'_v line. Then, the amount of void ratio reduction due to collapse can be obtained from the void ratio difference between the stress points before and after soaking of water. The vertical stresses before and after soaking of water are identical.

Now, let us try to apply the method described above to the pond proposed here. Although the behavior of the pond is two-dimensional, for simplicity we assume that the behavior is one-dimensional. Assuming that the field water content is consistent with the driest e - log σ'_v line obtained from the oedometer test, and the mean wet unit weight of fill and foundation soils is about 15 kN/m^3, the mean value of vertical stress will be about 23 kPa. Based on the results of oedometer tests, the change of void ratio due to collapse for this mean vertical stress ranges between 0.05 for Red and Yellow loesses and 0.4 for Yellow soil. The volumetric strain is calculated by using the following equation,

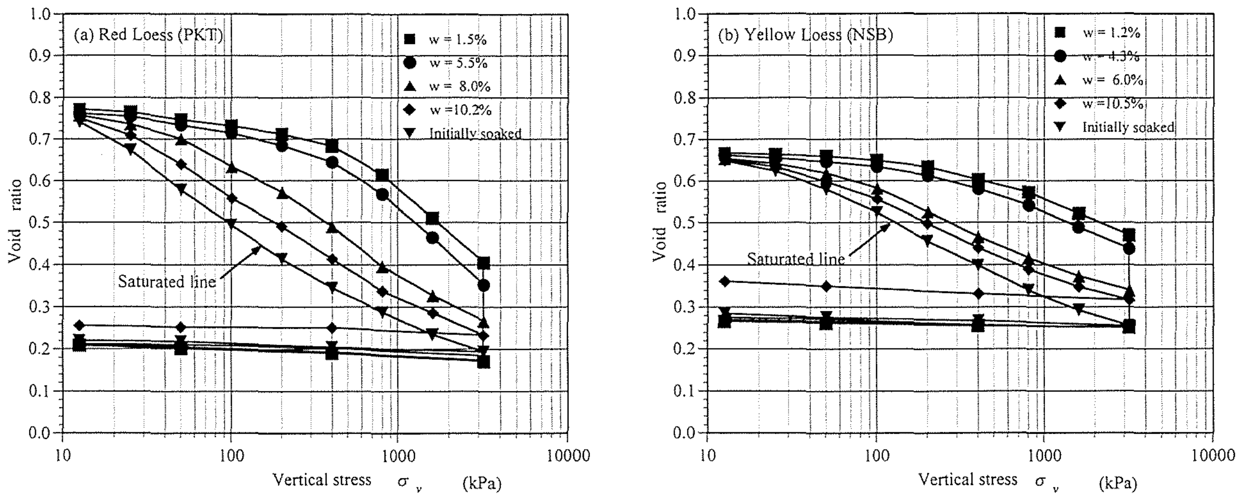

Fig. 3. Oedometer test results of undisturbed Red and Yellow Loesses (data from Udomchoke[8])

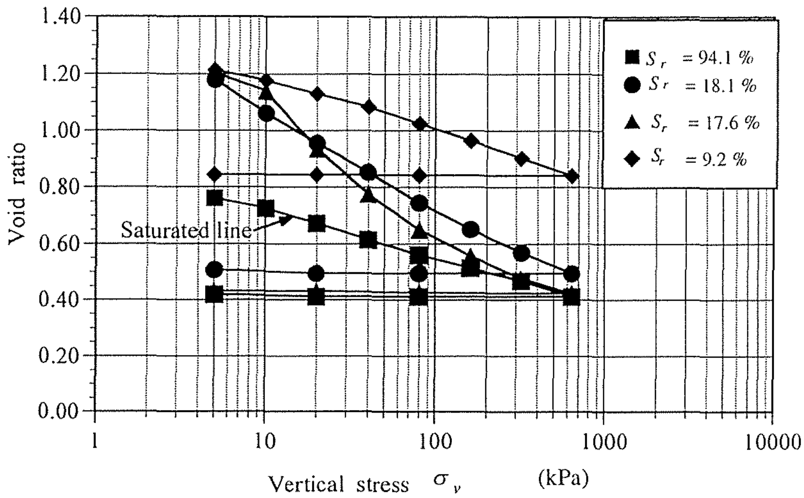

Fig. 4. Relationship between void ratio and vertical stress of Yellow soil obtained from oedometer tests[4]

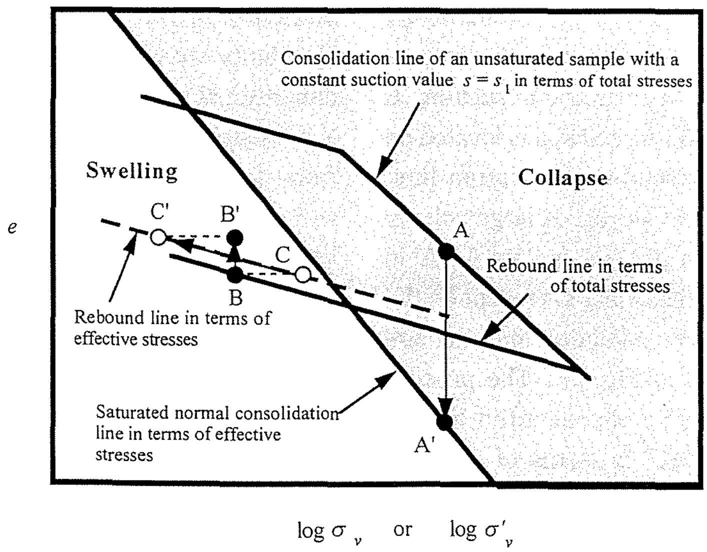

Fig. 5. Conditions of occurence of swelling and collapse

$$\varepsilon_v = \frac{\Delta e}{1 + e_b} \quad (1)$$

$$\Delta e = e_b - e_a . \quad (2)$$

Where ε_v is the volumetric strain due to collapse, e_b and e_a are the void ratios before and after soaking of water, respectively. The associated volumetric strains are 3% and 19%. Then, the amount of settlement reaches 4~29 cm. This is a simplified method. However, in more significant irrigation facilities, for example fill-type dams, a more sophisticated method must be used to estimate the amount of settlement. The method was described previously[3].

In order to reduce or prevent the settlement due to collapse, we can suggest the following two methods. The first is the pre-compaction method where the ground is compacted by using a back-hoe before excavation. The second is one of the stage construction methods where at first pre-excavation for constructing a temporary pond is carried out, then water is stored in the pond. During the filling of the reservoir, collapse may occur. After the settlement due to collapse ends, we can construct the pond as it was designed. The filling of the reservoir requires at least more than 3 months. It is desirable to construct ponds in low lands for the following two reasons: from the hydrological view and to reduce settlement associated with collapse. This is why the thickness of deposit of sandy and silty soils in low land is thinner than that in high land.

3) Slope resistance to erosion

There are several types of erosion; raindrop splash, sheet erosion, rill erosion and gully erosion[6]. In the case of raindrop splash, soil particles are detached by the impact of raindrops. In order to prevent this type of erosion, it is the best way to cover slopes with plants. As rill and gully erosions result from sheet erosion, the sheet erosion should be controlled in order to prevent rill and gully erosions. To prevent sheet erosion, there are generally two methods; decrease of flow velocity or absence of flow on slopes. If the ground can be cut vertically, there is no slope. Then, there is no flow on slopes. This method has been adopted in loess regions[7]. This method is only effective for unsaturated soils. In the case of ponds, the soil is filled with water after construction. Then the flow velocity should decrease. If we can decrease the velocity of flow, we can reduce the tractive force (stress) which corresponds to the shear stress due to the flow of water. The tractive stress is given by following equation:

$$\tau_t = \gamma_w h_m i \quad (3)$$

where τ_t is the tractive stress, γ_w the unit weight of water, h_m the hydraulic mean depth and i the hydraulic gradient.

The critical tractive stress τ_c for sandy soil is 0.00127 kPa[1]. Let us consider a condition where water flow on a slope is laminar, the tractive stress due to the water flow is critical and the slope is in equilibrium. This condition is shown in Fig. 6. From the equilibrium equation along the slope, we can obtain the following equation;

$$\tau_c \cdot dl \cdot 1 + \gamma' \cdot dx \cdot 1 \cdot H \sin\theta - \gamma' \cdot dx \cdot 1 \cdot H \cos\theta \tan\phi' = 0 \quad (4)$$

where γ' is the buoyant unit weight, dl the slope length of a given slice of soil, dx the width of the slice of soil, H the depth of the slice of soil, θ the incline of the slope and ϕ' the internal friction angle.

Supposing y=cos2 θ, Equation (4) becomes a quadratic equation of y as follows;

$$ay^2 + 2by + c = 0. \quad (5)$$

Then, y is

$$y = \frac{-b + \sqrt{b^2 - ac}}{a} . \quad (6)$$

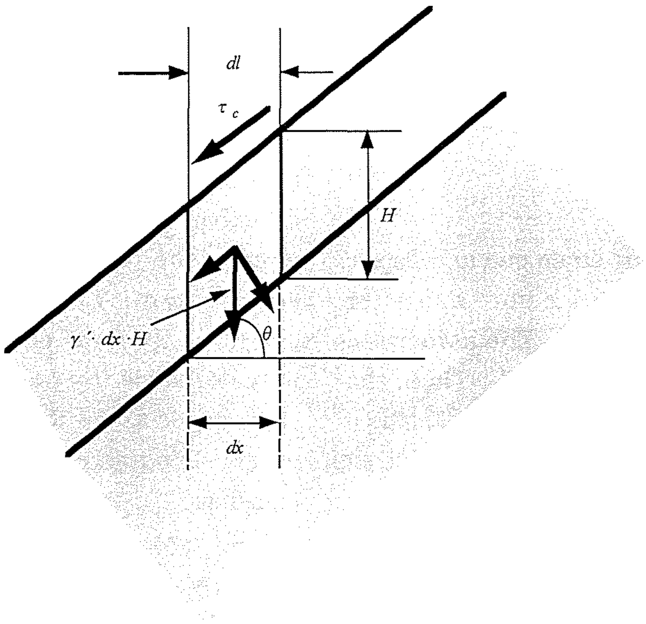

Fig. 6. Slope resistance to sheet erosion

Here, the coefficients a, b and c are given as

$$a = 1 + \tan^2 \tan \phi' \quad (7)$$

$$b = -\left(\frac{2\tau_c}{\gamma' H}\tan\phi'\right)\tan\phi', \quad (8)$$

$$c = \left(\frac{2\tau_c}{\gamma' H}\tan\phi'\right)^2 - 1. \quad (9)$$

For the sandy soils used in the construction of this pond, we will adopt the parameters τ_c = 0.00127 kPa, G_s = 2.67, γ_d = 14 kN/m^3, e = 0.87, γ_w = 9.8 kN/m^3. Then, γ' is 8.7 kN/m^3.

Calculating values of y for ϕ' = 25° and 30°, the value of y becomes a function of H as shown in Fig. 7. In this figure, supposing ϕ' =30°, and H = 0.001 m (equivalent to about 10 times the mean particle size D_{50}), we will obtain θ = 22.2°. Comparing this value with the slopes 1:2.5 (21.8°) and 1:2 (26.6°), the slope 1:2.5 is considered to be stable. Therefore, we will adopt 1:2.5 slopes.

4) Slope stability

In sandy soils, we do not expect the component of cohesion c of the soils when the soils are saturated. Then, we can only consider the internal friction angle ϕ'. Let us consider the slope stability of the pond shown in Fig. 2. As the incline of the slope is 1:2.5 (21.8°) and this incline is smaller than ϕ' = 30°, which is considered to be the mean value of sandy soils distributed in Northeast Thailand, then this slope is sufficiently stable.

Conclusions

Based on the test results, we proposed a type of small ponds. The standard cross-section of the small pond proposed is shown in Fig. 2. The dimensions of the small pond are as follows: 50~100 m length, 20 m width and 3 m height with 1:2 and 1:2.5 slopes. We investigated the performance of the small pond in relation to erosion and collapse. As a result of the investigations, we proposed a simplified method of determination of the occurrence of collapse as well as methods of the prevention of collapse. We also tried to estimate roughly the amount of settlement associated with collapse. In terms of erosion, the slopes of the pond proposed were found to be stable. Regarding the stability of more important irrigation facilities, we can use the method previously described[3].

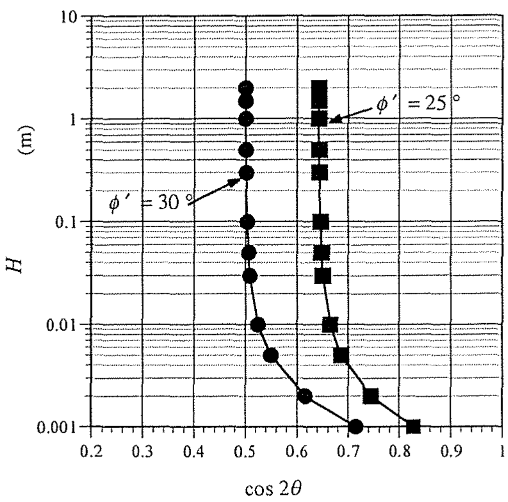

Fig. 7. Relationship between incline of slope θ and depth of soil slice H

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東北タイにおける小規模ため池の築造方法

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摘　要

東北タイに分布する典型的な土の力学試験の結果をもとに，小規模ため池の築造方法を検討した。東北タイの大部分は砂質系の土に覆われている。このような土の工学的な問題点は，水浸による沈下（飽和コラップス）とエロージョンである。したがって，この二つの問題点について検討することが，東北タイに適したため池を造る上で重要である。まず，飽和コラップスについて，その発生条件，発生した場合の沈下量の計算方法，および防止および抑止工法について検討した。発生条件は，間隙比を縦軸に取り，横軸に鉛直応力（対数表示）を取った空間に，現場での状態量（間隙比と鉛直応力の値）をプロットした時，その応力点が飽和正規圧密曲線の右側にある時にコラップスが生じ，左側では膨張が生じることを述べた。沈下計算は概略的な方法では，圧密試験の結果より計算する方法を示した。より詳細な方法としては，筆者らが提案した有限要素法による圧密解析手法を用いることができる。防止および抑止工法としては，仮掘削と湛水を行って，コラップスを引き起こした後に整形する，一種のステージコンストラクション工法を提案した。この工法は経済性にも優れている。エロージョンについては，シートエロージョンについて検討した。掃流力に対する斜面安定の計算から，安定的な傾斜角度を求める方法について述べた。以上の結果に基づいて小規模ため池の断面を決定した。

キーワード：飽和コラップス，エロージョン，ため池，不飽和土