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The safety behavior of agricultural reservoirs due to raising the embankment

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Abstract : This study was carried out to investigate safety evaluation of agricultural reservoirs due to raising the embankment. The seepage analysis and large-scale model test were performed to compare and analyze the pore water pressure(PWP), leakage quantity, settlement and piping phenomenon in the inclined core type and the vertical core type embankments. The PWP after raising the embankment showed smaller than before raising the embankment and the stability for piping after raising the embankment. The allowable seepage quantity and the allowable leakage for the steady state and transient conditions is within the range of safe management standard. After raising the embankment in the inclined core, there was no infiltration by leakage. For the vertical core, the PWP showed a large change by faster infiltration of pore water than in the inclined core. In a rapid drawdown, inclined core was remained stable but the vertical core showed a large change in PWP. Settlement after raising the embankment showed larger amounts of settlement than before raising the embankment. The leakage quantity before raising the embankment and the inclined core type showed no leakage. From the result, an instrument system that can accurately estimate a change of PWP shall be established for the rational maintenance and stabilization of raising the embankment for agricultural reservoirs.

Key words **:** Agricultural reservoir, Seepage analysis, Large-scale model test, PWP

I. Introduction

The basic objective of the "Project of Raising Agricultural Reservoir embankments", which has recently been carried out by the Ministry of Food, Agriculture, Forestry and Fisheries, is to enlarge technologies of the maintenance of water downstream and the supply of the irrigation water in agricultural areas, in terms of irrigation and flood control, and also to reinforce the agricultural reservoir which is vulnerable to disasters (KRC, 2009).

Especially, the project of raising embankments is a project that strengthens existing reservoir facilities, and turned out to be economically advantageous also by minimizing difficulties of a suitable site caused by developing new dams, and the environmental impact (MLTM, 2011). However, reservoirs in Korea, 64 % of those that are managed by municipal corporation, and 62 % of those that are managed by Korea Rural Community Corporation, have existed for 50 years or more since they were installed. In addition, 89 % of reservoirs are small-scale dams with less than 100,000 m^3 of available reservoir storage.

Currently, the agricultural infrastructure facilities consists of 17,679 of reservoirs, 7,178 of drainage pump stations, and 1,593 of sea dikes in Korea. 9,380 (53%) were installed before the 1945s, 6,203 (35%) during 1946-1971, and 80% of the reservoir have existed for 30 years or more (Fig. 1; KRC, 2009).

The construction period of raising the embankment has been decided for the period 2010-2015, a total number of 110 agricultural reservoirs is being constructed.

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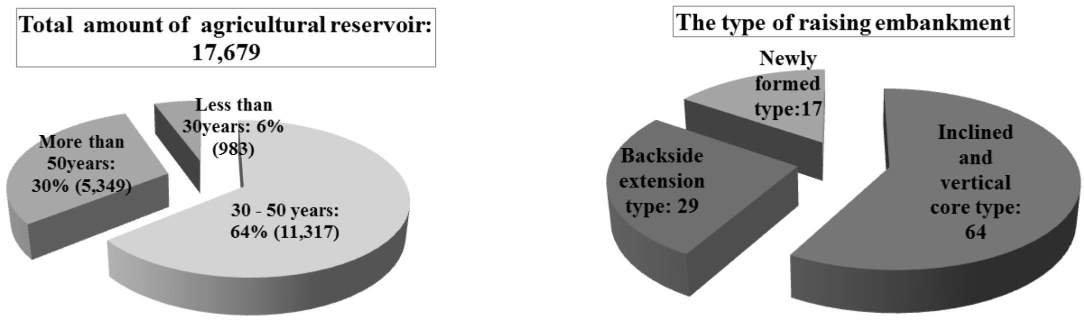


Fig. 1. Total amount of agricultural reservoir and types of raising the embankment.

Table 1. The scale of field reservoir.

Type	Total storage capacity (m^3)	Basin area (ha)	Length (m)	Height (m)	Height of raising embankment (m)	Length of spillway (m)	Type of raising embankment
Earth fill dam	4,710,000	1,574	288	17.1	2.80	111	Inclined core

The types of reservoir embankments are 64 for inclined and vertical core type, 29 for backside extension and 17 for a newly-formed embankment (Fig. 1). The heights of the embankments are 70 below 5 m, 20 for a range of 5 to 10 m, 6 for a range of 10 to 15 m, 7 for a range of 15 to 20 m and 7 for more than 20 m (MLTM, 2011).

However, in most areas for which the project of raising the embankment there are problems of slope stability in upstream and downstream slopes, for which the seepage analysis followed by the core installation is important. Moreover, the behavior before and after raising the embankment should be compared and analysed, which includes the possibility of differential settlement between the existing cores and the embankment material that is newly expanded, the settlement at the core, and the behavior in the downstream slope (Foster et al., 2000; Fell et al., 2003; Min and Lee, 2008; Kim and Lee, 2009; Lee and Noh, 2012).

Therefore, this study was carried out to evaluation the safety due to raising the embankment. Also, the seepage analysis and large scale model test were performed to compare and analyze the pore water pressure, quantity of leakage and settlement in the inclined core type and vertical core type.

II. Materials and Methods

1. Field reservoir condition

The field reservoir used for this study is shown in Table 1. A cross section of the reservoir before and after raising the embankment is shown as Fig. 2.

2. Soil properties

The grain size distribution curve and physical properties of used soil is shown in Table 2 (Lee and Lee, 2012).

3. Analysis method

As the embankment is already in the saturated condition before raising the embankment, the piping phenomenon in consideration of the saturated condition and the unsaturated condition has been analysed using SEEP/W 2007 program (GEO-SLOPE, 2007) on the basis of seepage analysis. The piping phenomenon has been checked with the methods by critical hydraulic gradient and allowable seepage quantity. In addition, the seepage analysis has been conducted by

Table 2. Material properties used soils.

Division	Unit weight (γ_{sat} , KN/m^3)	Permeability coefficient (m/s)	Cohesion (kPa)	Angle of Internal friction (phi)	Young's modulus (kPa)	Poisson's ratio	USCS
Bedrock	22.00	5.00E-11	31.85	35	200,000	0.30	GP
Core	19.57	3.11E-08	34.3	9	20,000	0.45	CL
Embankment	19.42	5.75E-07	16.66	24	25,000	0.35	SC
Filter	19.63	5.40E-05	0	33	30,000	0.33	SP
Riprap	22.56	1.00E-04	0	45	100,000	0.23	GP

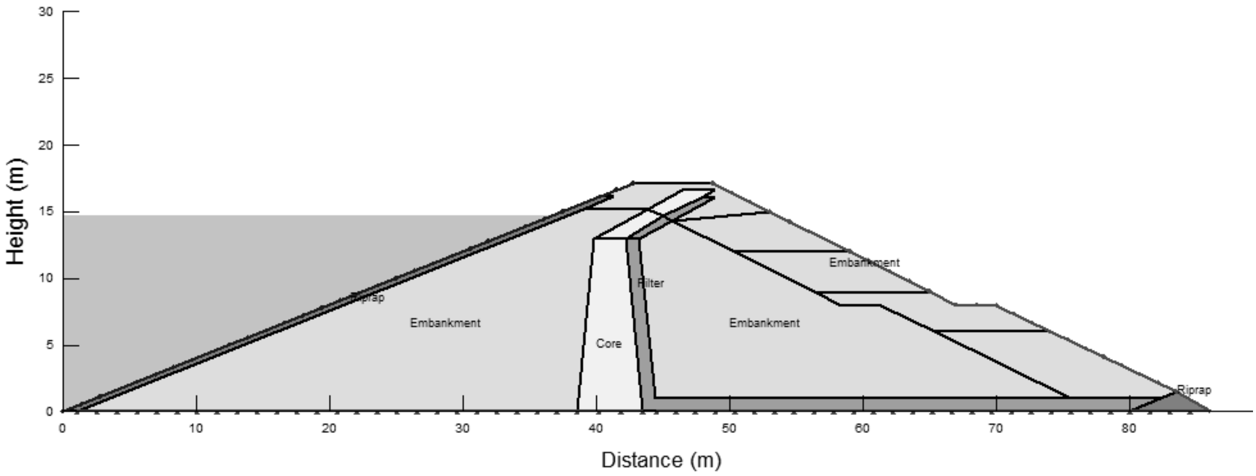


Fig. 2. A cross sections of the reservoir.

dividing the water level into the flood water level and rapid drawdown before and after raising the embankment (Lee et al., 2011).

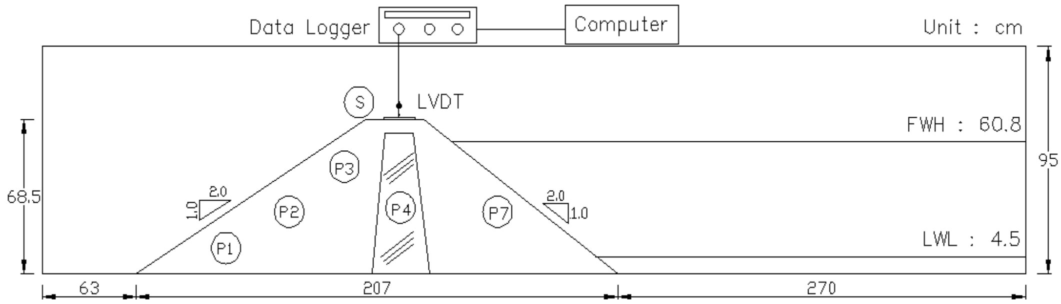
4. Large-scale model test

The large-scale experiment model is 126 cm in length, 540 cm in width, and 95 cm in height, and is made of concrete, iron and acrylic. Models of embankments before extension, and incline and vertical core types after extension are produced by reduction to 1/20 (Lee and Lee, 2012).

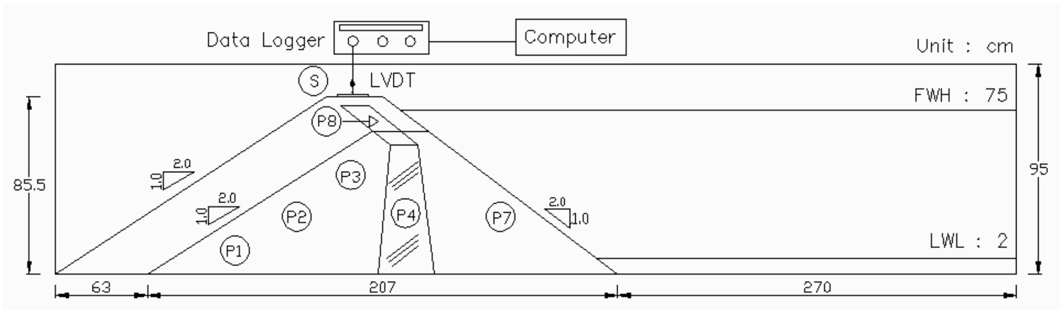
Fig. 3 (a) is a model before extension by applying 1 : 2.0 of incline. Fig. 3 (b) is a model of incline core type, and has been additionally filled up by about 17 cm in comparison with the model before extension. Fig. 3 (c) shows a model of the inclined core type. The stratified compaction has been performed into 95 % of maximum dry density by adjusting to the optimum water content. When the embankment was extended, the dry density turned out to be 1.655 gf/cm^3 in the fill-up and 1.585 gf/cm^3 in the core.

Fig. 3 (a), (b) and (c) shows the location of the pore water pressure (Ⓟ) before and after extension of the embankment. The installation depths of pore water pressure meter were 10-30 cm (P1: 10 cm, P2: 20 cm, P3: 30 cm, P4: 30 cm, P7: 20 cm) down from the top of the slope. The settlement was installed in the crest of the embankment.

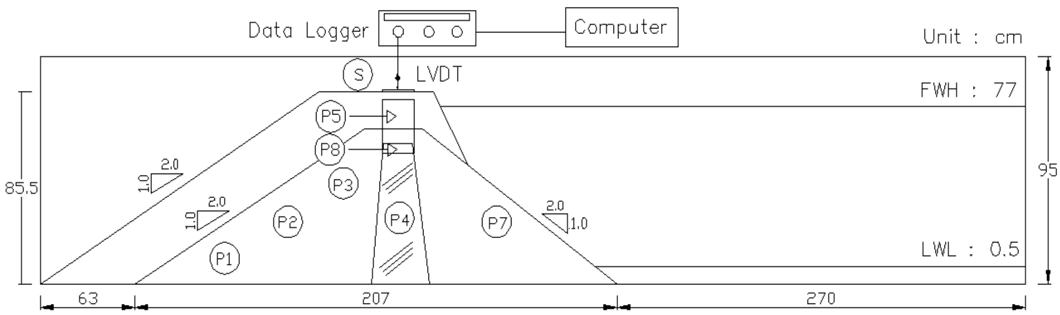
Each measured value was designed to be stored automatically by the data logger and the computer.



(a) Location of PWP before raising the embankment



(b) Location of PWP after raising the embankment in the inclined core



(c) Location of PWP after raising the embankment in the vertical core

Fig. 3. Model shape and location PWP gauge according to the core types.

III. Results and Discussions

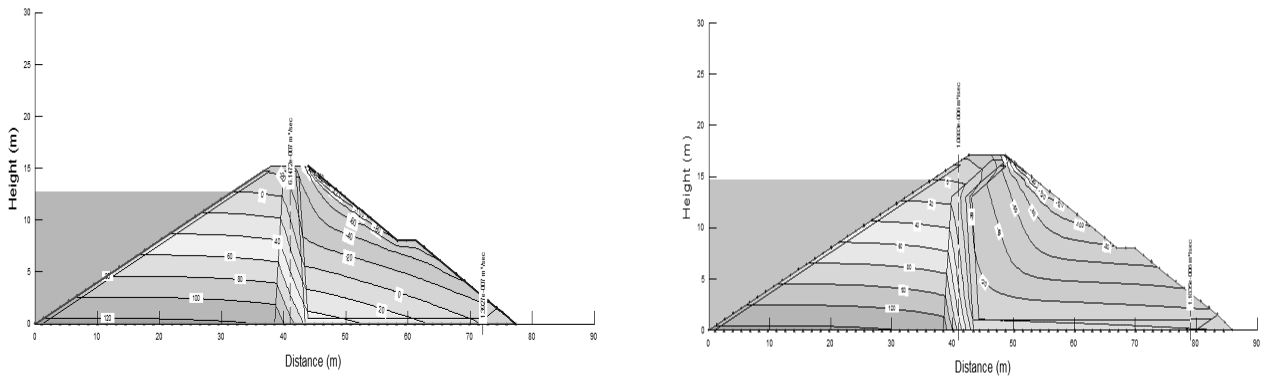
1. The variation of pore water pressure before and after raising the embankment

The seepage analysis was carried out under flood water level and rapid drawdown consideration the total storage of reservoir and the discharge quantity of spillway.

1) Steady state condition

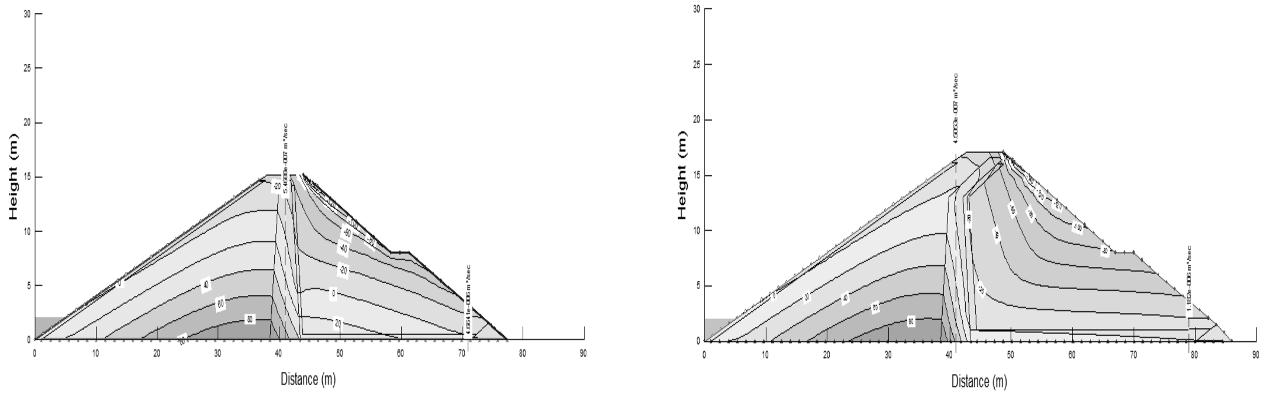
Fig. 4 (a) shows the distribution of pore water pressure (PWP) under the steady state before raising the embankment. The PWP shows positive (+) pore water pressure in the upstream slope and then it is gradually changing into negative (−) pore water pressure in the downstream slope. The PWP at the central part of the core is 93 (lower part) ~ −33 (upper part) kPa.

The seepage quantity in flood water level (12.76 m) turned out to be 6.15E− 07m^3/s/m at the center of the embankment and 1.39E−07 m^3/s/m at the front end of the downstream slope. The hydraulic gradient showed itself to be nearly zero in all the slopes. The



(a) Before (b) After

Fig. 4. Comparison of pore water pressure under steady state condition.



(a) Before (b) After

Fig. 5. Comparison of pore water pressure at rapid drawdown (one day).

critical hydraulic gradient is 0.821 and the safety factor is 8.212 in the result of seepage analysis, which determines it to be safe as it satisfactory with the safety management standard for piping, 2.0 and above.

Fig. 4 (b) shows the distribution of PWP after raising the embankment. The PWP at the central part of the core is 100 (lower part) ~ −20 (upper part) kPa. The seepage quantity in flood water level (14.70 m) turned out to be 1.09E−06 m^3/s/m at the center of the embankment, and 1.18E−06 m^3/s/m at the front end of the downstream slope. The hydraulic gradient showed itself to be 1 to 5 in the upper end of the downstream slope, and nearly 0 in the rest of the slopes, which determined the piping to be safe.

2) Transient condition

Fig. 5 (a) shows the distribution of PWP in rapid drawdown before raising the embankment. The PWP showed positive (+) pore water pressure in the upstream slope and no great change was seen in the downstream slope. When the flood water level (12.76 m) suddenly had rapid drawdown to dead level (2.0 m), the seepage quantity gradually decreased to be 5.47E−07 m^3/s/m at the center of the embankment and 4.66E−06 m^3/s/m at the downstream slope.

Fig. 5 (b) shows the case of rapid drawdown after raising the embankment. The PWP turned out to have remained continuous around the upstream slope, which is judged that the upstream slope is in an instability state and the slope stability needs to be analysed.

When the flood water level (14.70 m) suddenly had rapid drawdown to dead level (2.0 m), the seepage quantity gradually decreased to be 4.51E-07 m^3/s/m at the center of the embankment and 1.18E-06 m^3/s/m at the downstream slope.

The hydraulic gradient before raising the embankment gradually decreased in the upstream slope, the safety factor showed itself to be 1.0 or below in the upper part of the downstream slope, which showed an instability state for the piping. However, the hydraulic gradient after raising the embankment, turned out to be nearly 0 in the downstream slope, which proved that the stability increased for the piping in comparison to before raising the embankment.

2. The piping phenomenon caused by the allowable leakage quantity

Table 3 shows the result of seepage analysis under the steady state and transient conditions.

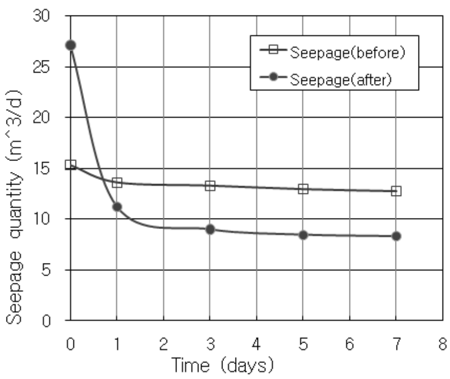
Fig. 6 (a), (b) shows the steady state before raising the embankment with changes into the transient condition during rapid drawdown. The seepage quantity per day and the leakage quantity per 100 m decreases slightly in the beginning, but they decrease steadily without a great difference after one day. However, when the steady state after raising the embankment changed into the transient condition, the seepage quantity and the leakage quantity decreases greatly; approximately 2.4 times in the early stage, and after one day decreases steadily. The reason why there was no great difference in each time of rapid drawdown under the transient condition is judged to be because there was not enough time for dissipating the PWP with the water level falling too quickly.

3. The variation of PWP by model test

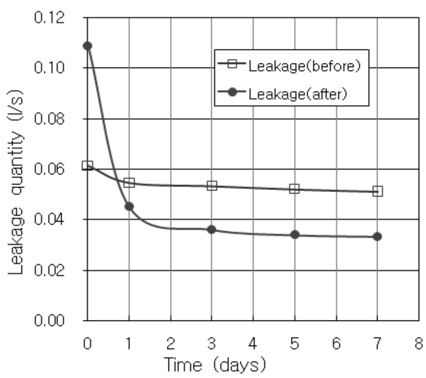
Fig. 7 shows the variation of PWP in flood water level (60.8 cm) for 98 hours before the raising embankment. The PWP (P4) at the core showed itself nearly 0 gf/cm^2

Table 3. Results of seepage analysis under the steady state and the transient condition.

Division		Before raising the embankment: Seepage quantity/1day (m^3/d)	Before raising the embankment: Leakage quantity/100m (l/sec)	After raising the embankment: Seepage quantity/1day (m^3/d)	After raising the embankment: Leakage quantity/100m (l/sec)
Steady state		15.30	0.0615	27.12	0.109
Transient (days)	1	13.61	0.0547	11.22	0.0451
	3	13.29	0.0534	8.98	0.0361
	5	12.94	0.0521	8.46	0.0340
	7	12.74	0.0512	8.31	0.0334



(a) Seepage quantity



(b) Leakage quantity

Fig. 6. Comparison of the steady state and the transient condition under rapid drawdown.

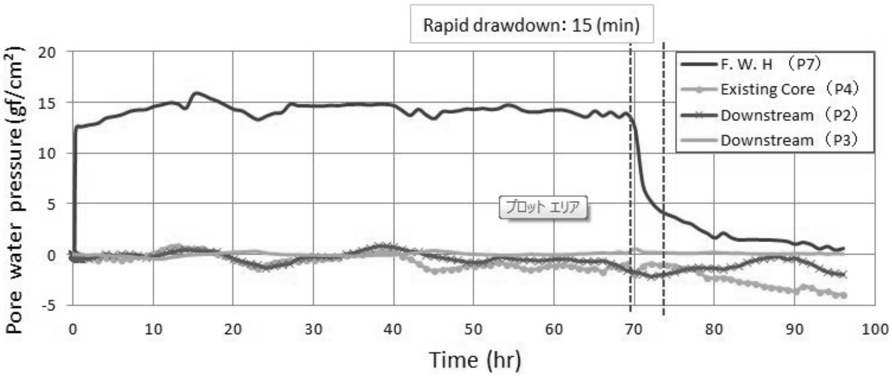


Fig. 7. Variation of PWP before raising the embankment.

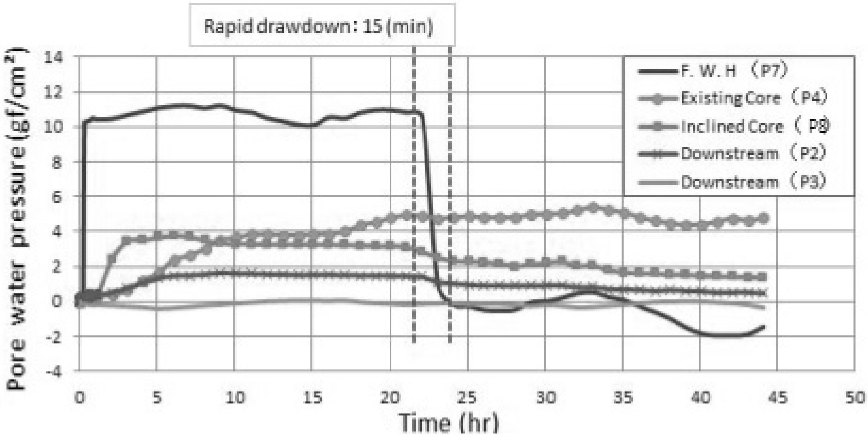


Fig. 8. Variation of PWP after raising the embankment in the inclined core.

and it slowly decreased as time passed. The PWP in downstream slope was kept consistently at 0 gf/cm^2, which proved that there was no effect of water leak caused by infiltration.

Fig. 8 shows the variation of PWP for 44 hours after raising the embankment in the inclined core. In flood water level (75 cm), the PWP at the core (P4) didn't show substantial change in the early stage, but as time passed, the PWP slowly increased. The PWP at the core (P8) increased sharply in the beginning, and was gradually kept consistent; however, it showed a high PWP. In downstream, the PWP in the center (P2) slowly increased as time passed to show itself consistently within the range of 1.5 to 1.8 gf/cm^2. The PWP in the upper part (P3) was maintained at approximately 0 gf/cm^2 at the time.

After rapid drawdown (15 min), the PWP at the existing core (P4) maintained consistently within the range of 4 to 5 gf/cm^2, and the PWP at the upper part (P2) and the core (P5) gradually decreased as time passed. The PWP in the upper part (P3) showed around 0 gf/cm^2. On the whole, when the core had been constructed as an incline core type, the pore water was infiltrated into the core; however in the downstream no infiltration by water leak took place to prove stability.

Fig. 9 shows the variation of PWP for 44 hours after raising the embankment in the vertical core. In flood water level (77 cm), the PWP at the existing core (P4), upper core (P8) and the boundary surface (P5) increased sharply in the early stage, and was maintained consistently within the range of 3 to 4 gf/cm^2. In the downstream, the PWP at the center (P2) showed (−) PWP in the beginning; however as time passed, it suddenly increased and was consistently maintained within the range of 2 to 3 gf/cm^2. The PWP at the

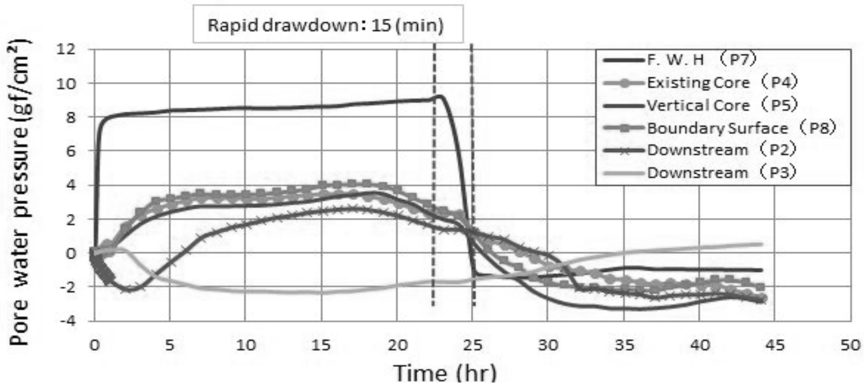


Fig. 9. Variation of PWP after raising the embankment in the vertical core.

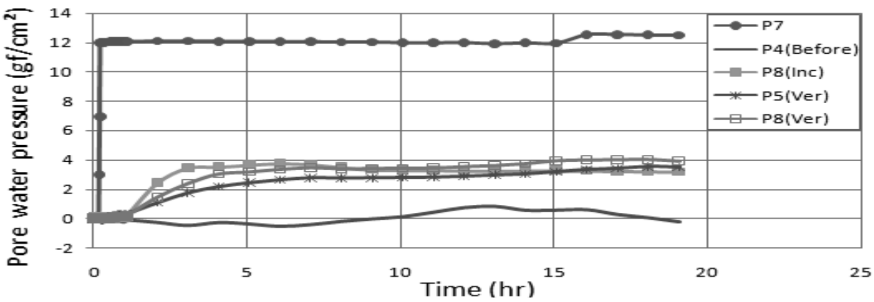


Fig. 10. Variation of PWP in the vertical and inclined core.

upper part (P3) showed kept at −2 gf/cm^2.

After rapid drawdown (15 min), the PWP at the existing core (P4), upper core (P5), the boundary surface (P8) and the center (P2) sharply decreased, and then stabilized. The PWP in the upper part (P3) didn't show great change in the beginning, but gradually increased as time passed. It is judged that it does not decrease even in the rapid drawdown because the upper part of the slope was saturated.

In general, the results are judged that the vertical core type is more vulnerable to infiltration than the incline core type. And it seemed to be a high possibility of occurrence of piping in downstream.

4. The variation of PWP according to core type

Fig. 10 shows the change of PWP at the core before the extension, the incline core and vertical core types. The PWP at the core before the extension (P4) showed consistently around 0 gf/cm^2 without distinct change. The PWP of the incline core (P8), vertical core (P5) and the connection (P8) of the vertical core increased in the early stage, and then was maintained consistently as the water level changed. It is judged that the PWP was infiltrated both the incline and vertical core type.

5. The variation of settlement

Fig. 11 shows the distribution of settlement according to the time before and after the extension. The settlement before the extension slowly decreased, and after the extension greatly settled; hence it is judged that the core expanded horizontally and the saturation caused by the infiltrated pore water brought about great settlement.

6. The variation of PWP due to leakage quantity

Fig. 12 shows the variation of PWP for 70 hours before the incline core type and the vertical core type

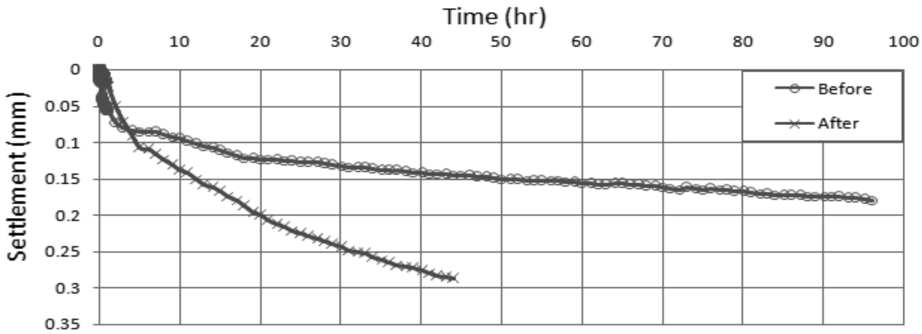


Fig. 11. Variation of settlement before and after raising the embankment.

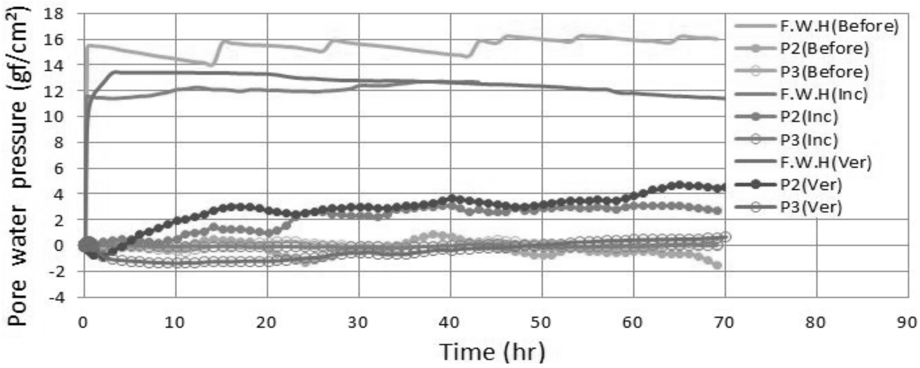


Fig. 12. Variation of PWP by leakage of downstream.

in the downstream slope. The PWP at the middle part (P2) and the upper part (P3) before raising the embankment showed consistently at 0 gf/cm^2. The PWP at the center (P2) of the inclined core type slowly increased to be kept consistently at 2 to 3 gf/cm^2, and the PWP at the upper part (P3) was maintained constantly at 0 gf/cm^2. In addition, no leakage quantity was measured.

In the vertical core type, the PWP in the middle (P2) greatly increased to be maintained at 3 to 5 gf/cm^2 in the early stage. The PWP in the upper part (P3) did not show great change in the beginning, but slowly increased as time passed. The leakage quantity measured of 160 liters after approximately 70 hours. It is judged that there is a high probability of piping phenomenon.

Ⅳ. Conclusions

This study was carried out to evaluation the safety of the agricultural reservoirs due to raising the embankment. The seepage analysis and large-scale model were performed to compare and analyze the PWP, leakage quantity, settlement and piping phenomenon. The seepage analysis was used for the steady state and transient conditions, and an experiment with a large-scale model was performed in the inclined core type and the vertical core type embankments.

1. After the rapid drawdown, the PWP distribution for the steady state and transient conditions turned out to have remained continuous around the upstream slope, which is in an instability state. It judged that the instability state needs to be evaluated by the slope stability analysis. The hydraulic gradients before raising the embankment showed a little instability for piping phenomenon, and after raising the embankment increased the stable state.
2. The allowable seepage quantity and the allowable

leakage for the steady state and transient conditions were within the range of safe management standards. The embankment showed to be safe against the piping. When the steady state after raising the embankment changed into the transient condition, it decreases greatly at approximately 2.4 times in the early stage.

3. In the model test for the inclined core type, the variation of PWP rapidly increased at the upstream slope, yet there was no infiltration by leakage. For the vertical core, the PWP showed a large change by faster infiltration than in the inclined core. The vertical core type is more vulnerable to infiltration than the incline core type. Settlement after a raising the embankment showed larger amounts of settlement than before raising the embankment.
4. The leakage quantity before raising and the inclined core type showed no leakage. Leakage in the vertical core type was measured 160 l during 72 hours.

From the result, an instrument system that can accurately estimate a change of PWP shall be established for the rational maintenance and stabilization of raising the embankment for agricultural reservoirs.

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