Performance of Seepage Control System in the Largest RCC Dam in Thailand

Leistung des Sickerwasser-Überwachungssystems in der größten RCC Staumauer in Thailand

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Abstract

The Khun Dan Prakarnchon Dam, the largest RCC gravity dam in Thailand, has been completed since 2005. On the 1st and 2nd year of impounding, the pressures under the dam foundation were carefully monitored. For the 1st impounding, the piezometric heads were activated when the water level has been raised above 25 m above the dam foundation level. The discharges of foundation and dam body drains which were measured by 80 V-Notch weirs in the dam galleries show 50% decreasing from the 1st to 2nd year mainly because of self-healing in micro-cracks in the dam body.

Zusammenfassung

Die Khun Dan Prakarnchon Staumauer, die größte RCC-Schwergewichts-Staumauer in Thailand, ist im Jahr 2005 fertiggestellt worden. Im ersten und zweiten Jahr des Einstaus wurde der Druck unter der Staumauer sorgfältig überwacht. Beim ersten Einstau wurden bei einem Wasserstand von 25 m Erhöhungen des Porenwasserdruckes festgestellt. Sickerwasser-abflüsse in Gründung und Staumauer wurden durch 80 V-Messwehre in den Kontrollgängen gemessen. Sie zeigen einen Rückgang der Abflüsse vom ersten zum zweiten Jahr um 50 %. Dies dürfte hauptsächlich auf die Selbstheilung von Mikro-Rissen im Mauerkörper zurückzuführen sein.

1 Dam characteristics

1.1 Dam Features

Khun Dan Prakarnchon dam (former Khlong Tha Dan dam) consists of two roller compacted concrete (RCC) gravity dams separated by rock hill. The dam volume of about 5 million m^3, and it was classified as the world largest RCC gravity dam in 2004. The typical section and profile of RCC dam are shown in **Figure1**. The features of the dam are summarized as following:

Maximum dam height [m]	92
Crest length [m]	2 600
Maximum width of foundation [m]	86
RCC dam volume [million m^3]	50
Reservoir volume [million m^3]	224

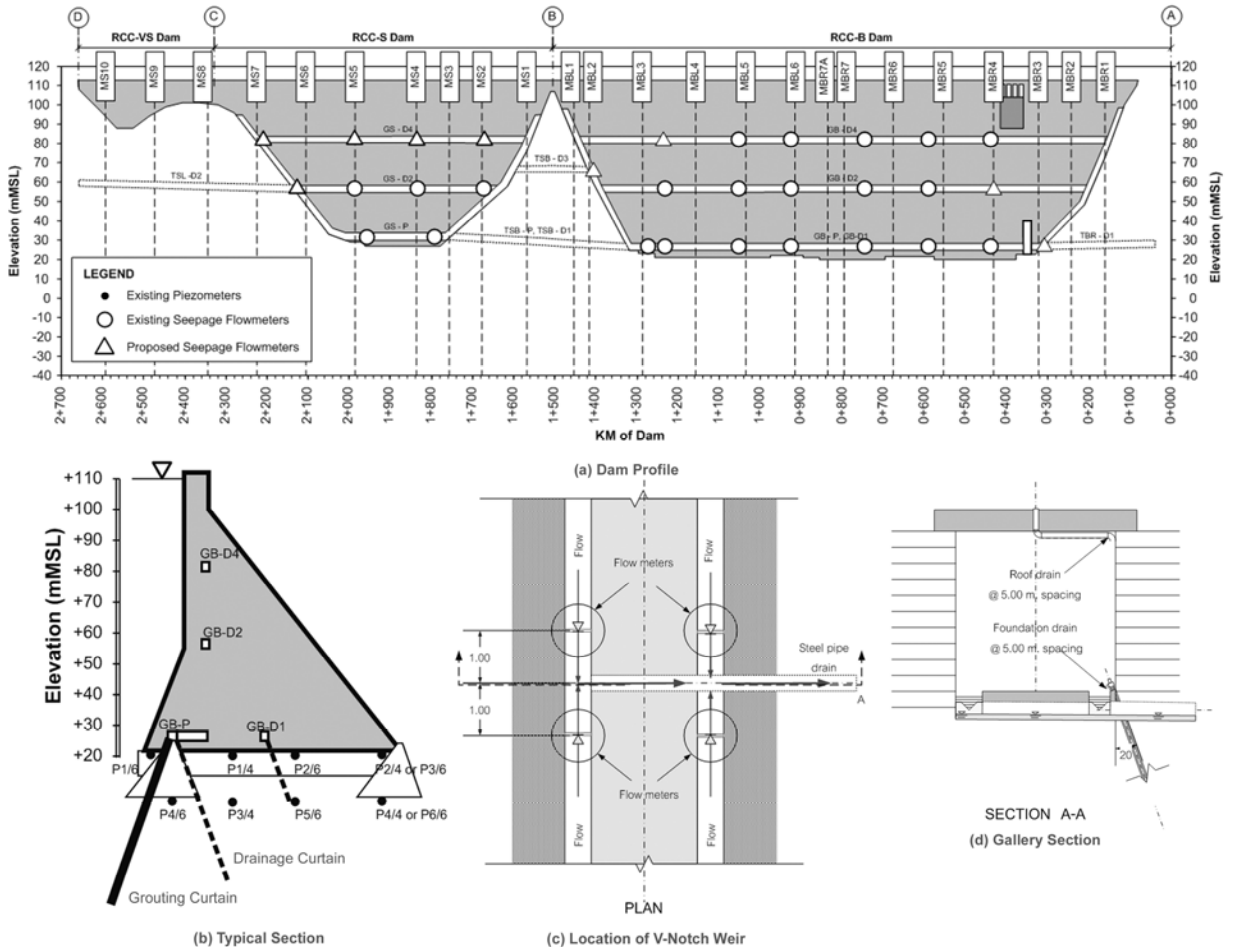


Figure 1: Typical section of dam and instrumentation [2, 3]

Outer surfaces of the dam body are slipformed concrete wall and on the upstream face, the thin reinforcement concrete shell is provided for watertightness. Typically, the vertical contraction joints made of polyethylene sheet were provided on every 40 meters along the dam axis. The rubber waterstop and vertical pipe drain on the upstream of facing concrete is provide to block the seepage water through the joint. The seepage in the dam body is intercepted by the vertical drain holes of 100 mm. in diameter at 5 m. spacing. The seepage in rock foundation is controlled by a line of grouting curtain and 2 lines of drainage curtain. The foundation grouting of cement-bentonite mixture was injected in the rock foundation down to 60 m. at the angle of 20° from the bottom gallery. The 1st and 2nd drainage curtains were done by drilling to the depth of 40 m and 15 m beneath the foundation respectively. The seepage water is collected into the dam gallery and then flows by gravity through the steel drain pipe to the downstream slope of the dam.

1.2 Geology of dam site

The project is located on the rim of the Korat Plauto. The undifferential Permo-Triassic Volcanic rocks is the major rocks formation over the entire project area This rock unit is consisted mainly of rhyolite, andesite, rhyolitic and andesitic tuffs, agglomerates and volcanic breccia. It is known as Khao Yai Volcanic Formation.

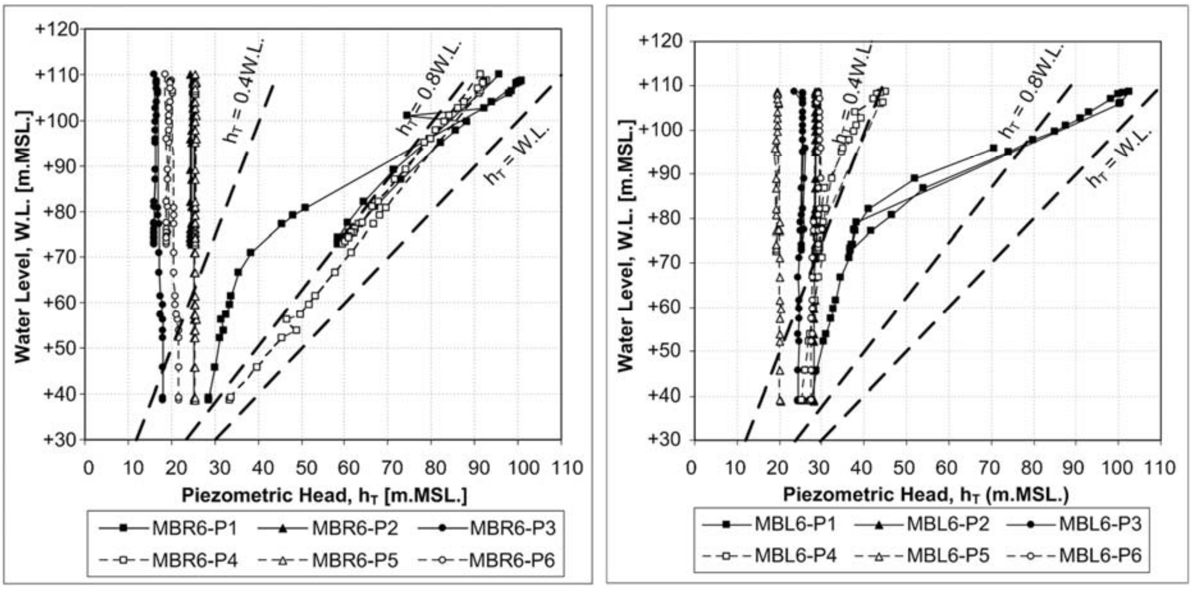
On the dam foundation, the major rock of the right bank are mainly pyroclastic rocks which consists of tuff and agglomerate with basalt and andesite alternatively. On the left bank, the foundation is founded on lava rocks that classified as rhyolite, andesite and basalt. The rosette diagram of 5500 joints plane shows that the main joint sets align on N 20° to 50° W with dip angle 60° to 80° to NE and SW. The other joint set aligns on S 80° to 90° W with dip angle 60° to 80° to SW. The result of permeability test (Lugeon) which performed during site investigation and construction were evaluated permeability of rock. From the Lugeon map [4] shows that the most previous zone is around 0+600 and 0+700 and the permeability decreases with depth for all rock types.

2 Seepage Monitoring

During construction period, 106 piezometers and 8 observation wells were installed. The piezometers were installed in 2 typical patterns, namely Section A with 6 piezometers and Section B with 4 piezometers as illustrated in Figure 1. The upper set of piezometers were placed at 1 m below the dam foundation level, and the rest were placed at 16 m. At the end of the construction, 80 seepage flowmeters were installed to observe the seepage loss and monitor the efficiency of the drainage system. The 90 degree V-Notch steel plate weirs were installed in the gutter in the galleries at the upstream of the outlet pipes[3].

2.1 Seepage Pressure and Uplift Forces

Pressures beneath the dam foundation are continuously measured from the construction period through reservoir impounding. The relationships between the pressure and reservoir water level are illustrated in **Figure 2**. It shows that the pressures on the downstream area of the grouting curtain on P2/6 and P5/6, P3/6 and P6/6 are rather constant because of the effective of the foundation drains. But the pressure on P1/6 and P4/6 show the histeresis loop relationship with the reservoir water level on the initial impounding. This behavior may cause by compressible air bubbles trapped in the dam foundation. When the pressure increases due to rising of reservoir level, the air bubbles are compressed and finally dissolved. After reservoir level drawdowns, the bubbles rebound again. So that some voids in rock foundation still were not saturated by water on the 1st impounding. The relation of pressure v.s. reservoir level of P1/6 and P4/6 are nonlinear and irreversible. The pressures difference from P1/6 to P4/6 indicates the head loss through grouting zone of 20 to 40% of the total head loss.



(a) MBR6 (b) MBL6

Figure 2: Pressure and uplift beneath dam foundation [3]

Table 1: Efficiency of uplift controls

Date		05-10-28	05-12-28	06-07-24	06-10-30
Upstream head, H_1 [m]		83,9	86,4	73,8	87,5
Piezometer No.	1/6	78,2	79,1	48,6	75,1
	4/6	22,0	21,8	12,9	19,8
	1/4	7,3	7,5	5,0	5,4
	2/6	6,6	6,6	6,4	6,3
	3/6	3,5	3,5	4,0	4,3
Downstream head, H_2 [m]		0	0	0	0
Total uplift measured, U_1 [kN/m]		11 400	11 520	8440	10 770
Total uplift in design, U_2 [kN/m]		18 500	19 010	16 870	19 720
% Efficiency (U_1/U_2x100)		61,6	60,6	50,0	54,6
SFF (FS against Sliding)		3,4	3,2	4,4	3,1
Compressive stress [MPa]		1,13	1,21	0,85	1,23

The pressures on section A and nearby section B are combined to determine uplift force as results shown in **Table 1**. When the reservoir water at normal high water level (NHWL) or 90 m., the total uplift forces beneath dam foundation are ranging from 10 800 and 11 400 kN per linear m. comparing to 19 000 kN from the design. The sliding stability of the dam body, indicates by factor of safety against sliding (SSF) shown on equation (1).

$$SSF = \frac{A \cdot c + (V - U) \cdot \tan \phi}{H} \qquad (1)$$

where

H = Σ horizontal forces, V = Σ vertical forces

U = uplift force, A = area of dam sliding surface

c and Φ = cohesion and friction of the sliding surface between dam and rock.

And the maximum compressive stresses at the dam-body toes are checked by equation (2).

$$\sigma = \frac{V}{b} + \frac{6 \cdot M}{b^2} \qquad (2)$$

where

b = width of the dam base, M = moment about base neutral axis

The ultimate compressive strength of the RCC is targeted for 10 MPa. While the allowable compressive strength for the usual loading conditions was set at 3.33 MPa [1].

When the density of RCC equals to 21 kN/m^3, c equals to 0,6 MPa and Φ equals to 45° [1]. The values of SSF and compressive stresses in case of NHWL are given as summarized in Table 1. Range of SSF are from 3,1 to 3,4 which are higher than the required factor of safety of 3,0, and the maximum compressive stress at the dam toe is less than 1,3 MPa.

2.2 Seepage discharge

The total seepage through the dam and the foundation had been totally 25 000 m^3/day on 2005 and decreased to 12 000 m^3/day in 1 year later. The decrease due to the formation of calcium carbonate compound filling in the voids of interfacial layers of RCC and the subsequence corrective chemical grouting. The distribution of discharge on various location on dam in case of NHWL (Figure 2) shows by the average seepage in the discharge steel drain pipes. The amounts of the seepage from V-Notch herein are presented as the flow rate per meter of dam. Figure 2 shows that the significant volume of 7,50 m^3/day/m has seeped through the dam body. The seepage through the dam is about 3 to 12 times higher than the seepage through the foundation.

Seepage through Foundation

On the first impounding, the water from the 1st and 2nd drainage curtains were measured amount of 3.50 and 0.25 m^3/day/m respectively. These flows decrease to 1.61 and 0.17 m^3/day/m in the second year. Although the efficiency loss of the foundation drain system is expected, but the uplift pressure under the dam foundation have not build up. The seepage through the RCC-S dam foundation equals to 0.9 m^3/day/m which is less than through the RCC-B dam foundation, because of the lower water level and the foundation rocks of RCC-S dam is relatively more impervious than those of RCC-B dam.

Seepage through Dam Body

Figure 3 shows that the seepage flows are ranged from 6,15 to 21,38, 2,16 to 12,52 and 0,07 to 1,54 m^3/day/m. for the lower, middle and upper galleries respectively. The unusual seepage occurred in RCC-S middle gallery due to the defect of contraction joint seal. However of later year, the flows had decrease to 2,71 to 15,60, 0,63 to 3,46 and 0,15 to 0,65 m^3/day/m for the lower, middle, upper galleries respectively. The seepage has reduced with time because of the cementation and self-healing processes in the dam body. The result of monitoring shows that the leakage volumes into the upper galleries directly varied with the water level.

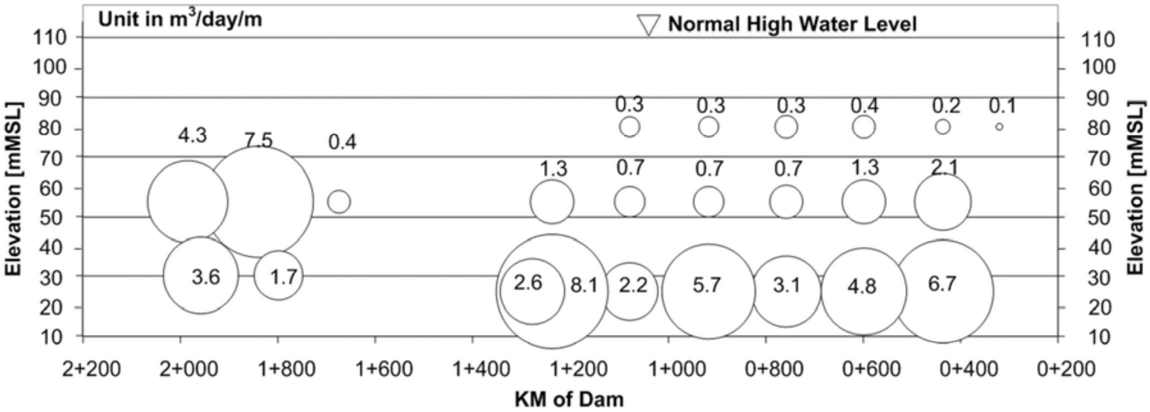


Figure 3: Distribution of seepage discharges [3]

3 FEM Analyses

During the construction, the seepage quantity and uplift force under the dam foundation were predicted by FEM based on the results of in-situ permeability tests of the rock foundation and the grouting curtain [3]. However, during impounding, the significant seepage flow in the dam body was observed. Then the seepage modeling is modified later by including seepages of the dam body with the foundation [4]. With varying coefficient of permeability of RCC in range of 10^{-10} and 10^{-8} m/s, the predicted seepage through the dam body are good agreement with the measured values. In case of the drainage is fully effective, the analyzed seepage through the dam is amount of 3,41 m^3/day/m. The discharges of the 1st and the 2nd drainage curtain equal to 1,52 and 0,36 m^3/day/m respectively. The comparison of the measured values of discharge and the predicted values in case of without the grouting curtain are given the efficiency of cutoff equal to 32 % for the second impounding.

Moreover, the uplift beneath dam foundation equals to 11 777 kN/m in the normal condition. The uplift pressure should be built up to 20 862 kN/m in case of the drainage curtains are failed [3]. It can be believed that the seepage control system is in the condition as designed.

4 Conclusion

1. Total of 106 piezometers, 80 V-Notch weirs were installed in Khun Dan Prakarnchon Dam, the largest RCC dam in Thailand. There monitoring yield the valuable data for evaluation of seepage behavior through dam body and foundation.
2. The sliding stability and the maximum stresses at toe of the dam are evaluated from the vertical, horizontal and uplift forces observed after the impounding. The SSF and maximum compressive stress at dam foundation are better than the required SSF of 3,0 and stress of 1,3 MPa. respectively.
3. The observed uplift force at reservoir NHWL indicates the effectiveness of drainage and grouting systems better than the predictions on the design and construction stages.
4. Significant water discharges through the dam body and foundation are totally 25 000 m^3/day on the first impounding and reduced to 12 000 m^3/day on the second impounding. The self sealing by calcium carbonate from concrete in the dam body is the main reason of void plugging.

5. The seepage through dam body are significant 3 to 12 times higher than from the foundation which is not expected during the design. So that additional FEM analyses of combined seepage for dam body and foundation had to be done to reconfirm the seepage behaviors.

Acknowledgements

Authors would like to thank Royal Irrigation Department (RID) and the RID's staffs at Khun Dan Prokarnchon (Khlong Tha Dan) Dam Project for the help and useful information.

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