

Seepage Analyses and Monitoring of Khlong Tha Dan Dam

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ABSTRACT

The Khun Dan Prakarnchon Dam, the largest RCC gravity dam in Thailand, has been completed since 2005. During the construction, the revised seepage analysis was performed according to the field data. 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. Uplift pressure on the foundation is lower than the prediction and the factor of safety against sliding and overturning can be checked during the operation.

INTRODUCTION

Khlong Tha Dan or Khun Dan Prakranchol Dam, one of the King's initiated projects, is considered to be the largest Roller Compacted Concrete (RCC) Dam in Thailand. The dam is 93 meters high, 2600 meters long with the dam volume of 5.4 MCM of concrete and reservoir volume of 224 MCM. It is situated at about 20 kilometers upstream from the city of Nakorn Nayok, one of the famous tourism area. The dam is founded on the complex volcanic rocks of rhyolite, andesite, rhyolitic and andesitic tuffs, agglomerates and volcanic breccia.

The permeabilities of the rock foundations are heterogeneous so a deep upstream grouting curtain and two drainage curtains are designed to control seepage and uplift pressure in the dam foundation. Seepage analysis during construction was reviewed according to the actual field pumping tests. And seepage behaviors during the first two years of impounding are monitored by 106 piezometers, 80 V-notch weirs and Observation wells. The actual monitoring data and previous seepage analyses are compared and verified to reflect the suitable modelling for future design. The actual seepage behavior can also ensure the safety evaluation of the dam at the initial stage of reservoir impounding.

PROJECT FEATURES

General

Tha Dan Dam is a storage dam on the upper Nakorn Nayok River at the foot of Khao Yai mountain range one of Thai's famous national park. About 93 percent of the average annual flow of 337 million cubic meters occurs during only 5 months from June to October causing flood on the downstream area almost every year. Since the catchment area is on the steep slope connected to the rather flat flood plain on the downstream thus the flash flood usually cause damage to the agriculture and residential area. On 1993, King Bhumipol initiated this project to Royal Irrigation Department(RID.) to investigate the possibility for construction the dam. The purposes of the dam are for irrigation, flood protection, domestic and industrial water supply and leaching of acid sulphate soil. After the extensive study, RID.

decide to construct the first Roller Compacted Concrete Dam mainly due to the lack of soil and rock for the conventional embankment dam. At the present, this dam is considered as the largest RCC dam in Thailand.

The project lay-out is shown on the Figure 1.

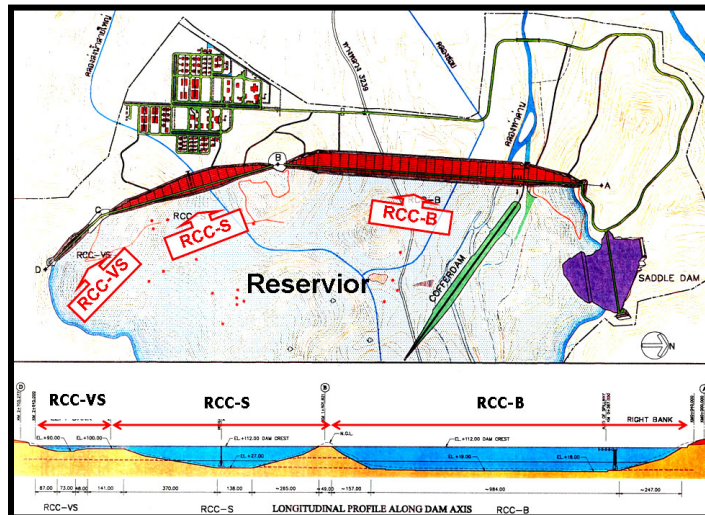
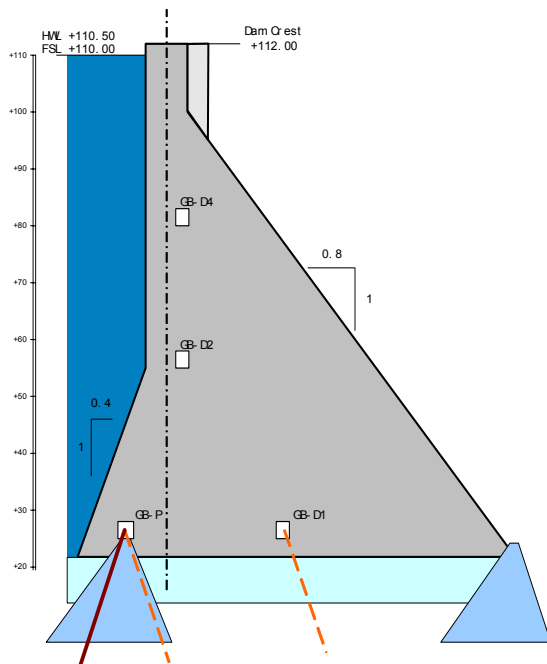


Fig. 1 Project layout



Dam features

The project consists of a series of dams as shown on Figure 1, the main RCC. dam (RCC-B), small RCC. dam (RCC-S), very small RCC dam (RCC-VS) and earth saddle dam. The topographical, geological conditions and the available construction materials reveal that the dam will be mainly RCC. gravity dam of the following features.

Maximum dam height	93 m.
Total crest length	2,600 m.
Maximum base width	78 m.
RCC. dam volume	5.47 m.c.m.
Reservoir volume	224 m.c.m.

Typical dam section is shown on Figure 2.

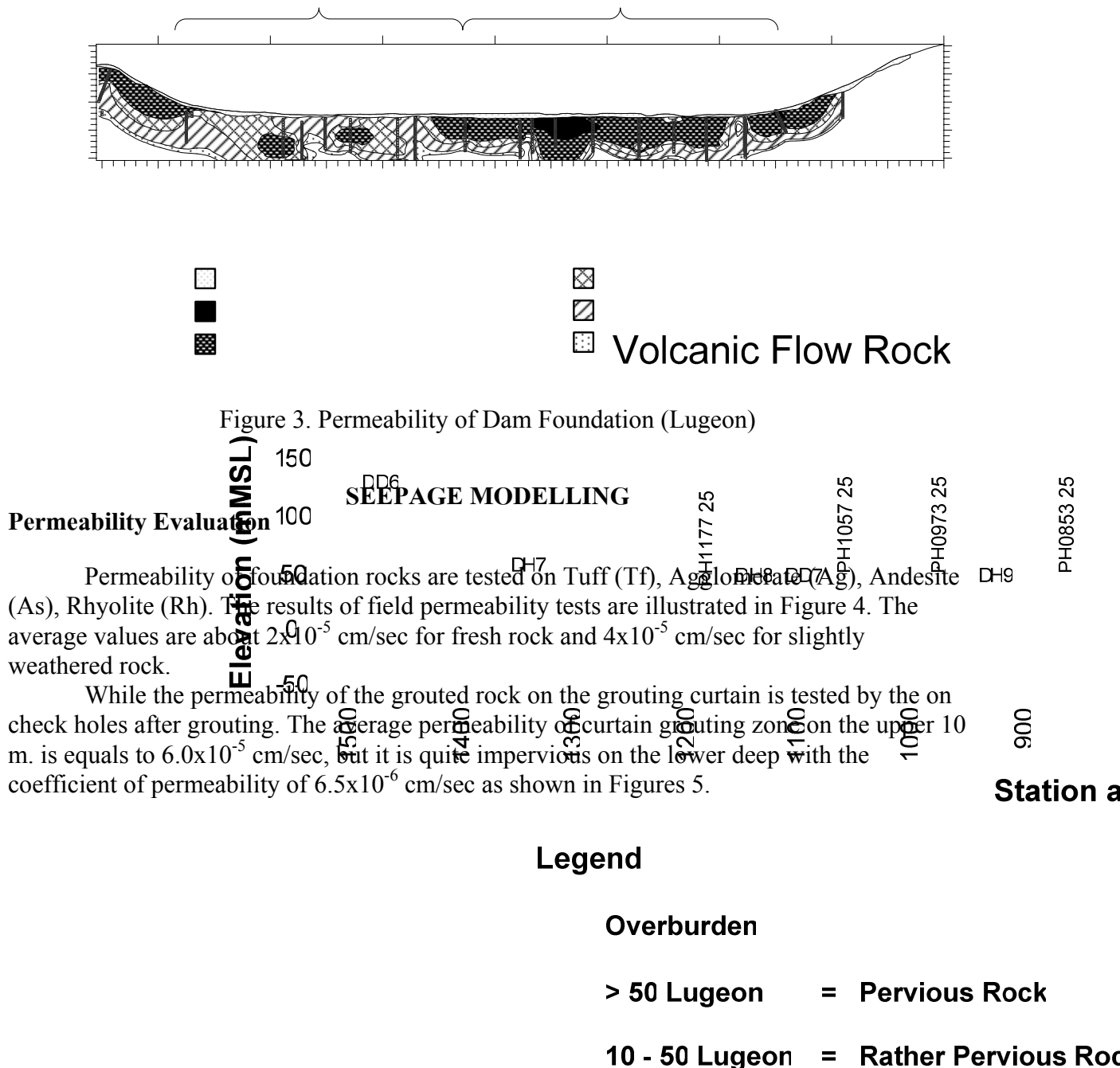
Fig. 2 Typical dam section

Geology of dam site and foundation

The project is located near the rim of the Korat Basin. Permo-Triassic Volcanic rocks is the main undifferentiated volcanic rocks over the dam site and reservoir area. This unit is consisted mainly of rhyolite, andesite, rhyolitic and andesitic tuffs, agglomerates and volcanic breccia. They are known as Khao Yai Volcanic Formation.

On the dam foundation, the bedrock is located at the shallow depth, only 2-10 m. from the existing ground surface. Bedrock mainly comprises of strong andesite, rhyolite, rhyolitic tuff, basalt, dacite and agglomerates. In general the quality of the rock mass is in good condition according to the Japanese Classification System or Geomechanics Classification

(RMR). However, a higher degree of jointing is observed on the area of the left abutment than on the right one. No major fault zone was presented along the dam axis. The dam foundation improvement was carried on by trimming blasting, cement grouting and finishing by the leveling concrete. Figure 3. shows the dam foundation permeabilities along longitudinal section in Lugeon.



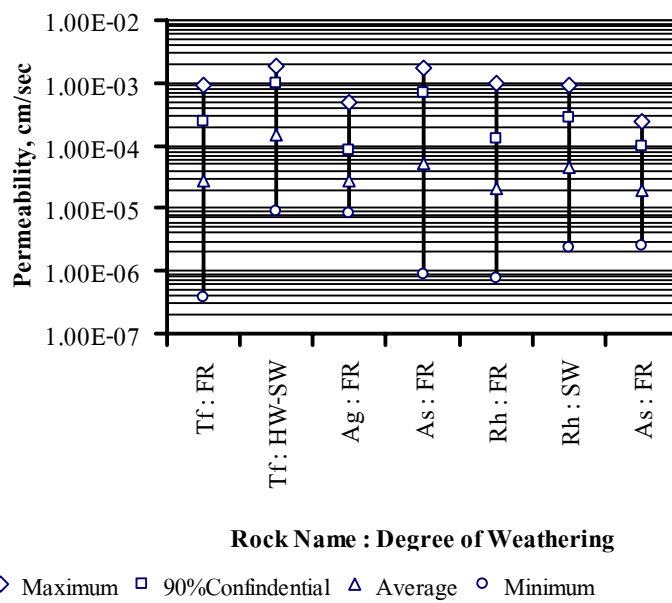


Figure 4. Distributions of permeability of foundation rocks

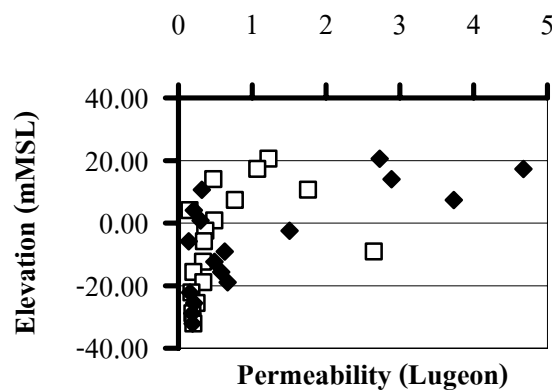


Figure 5 Permeability after curtain grouting from Lugeon test.

After statistical evaluation, the permeabilities of all materials involved in the analyses are summarized in Table 1.

Table 1 Coefficient of permeability used in 2D FEM

Zone	Coefficient of permeability (cm/sec)	k_v/k_x
Shallow foundation rock	4.6×10^{-4}	3
Deep foundation rock	4.9×10^{-6}	3
Grouting curtain	4.6×10^{-6}	1
Consolidation grouting	9.2×10^{-6}	1
Roller compacted concrete	1.2×10^{-4}	0.5
Convention concrete	1.0×10^{-6}	1

Plan View Analyses

On dam foundation, the series of drain holes are drilled at every 5.00 m. interval parallel to dam axis for both primary and secondary drainage as shown on Figure 6. Although the d/s head at the drain holes is equivalent to drain elevation at the drainage gallery. But the heads between drain holes are higher. In order to establish the d/s head, thus 2-D plan view analysis has to be performed first to get the average heads of the drain curtains. The result of equivalent hydraulic heads at d/s drains are as shown on Figure 4.

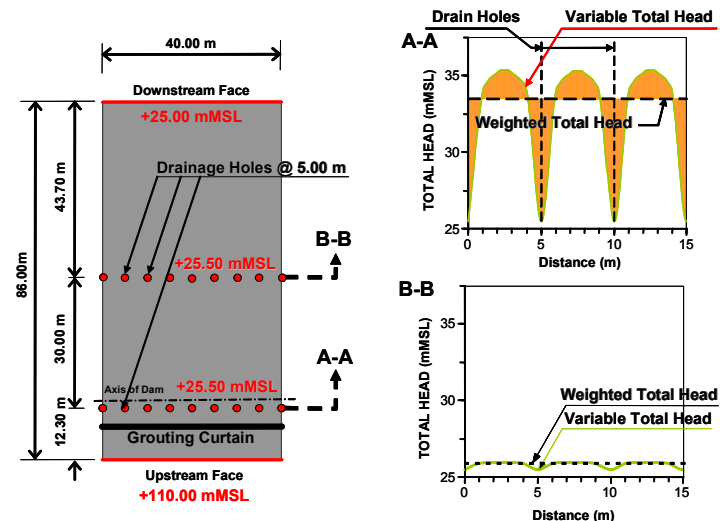


Figure 6. Plan View Seepage Analysis for Drainage Heads

Dam Section Analysis

The 2-D seepage analysis of the main dam cross-section is analyzed through the critical section. Steady state flow is assumed with the normal high water level (NHWL) in the reservoir and tail water at the drainage gallery. The FEM Mesh of the dam section is as illustrated on Figure 7.

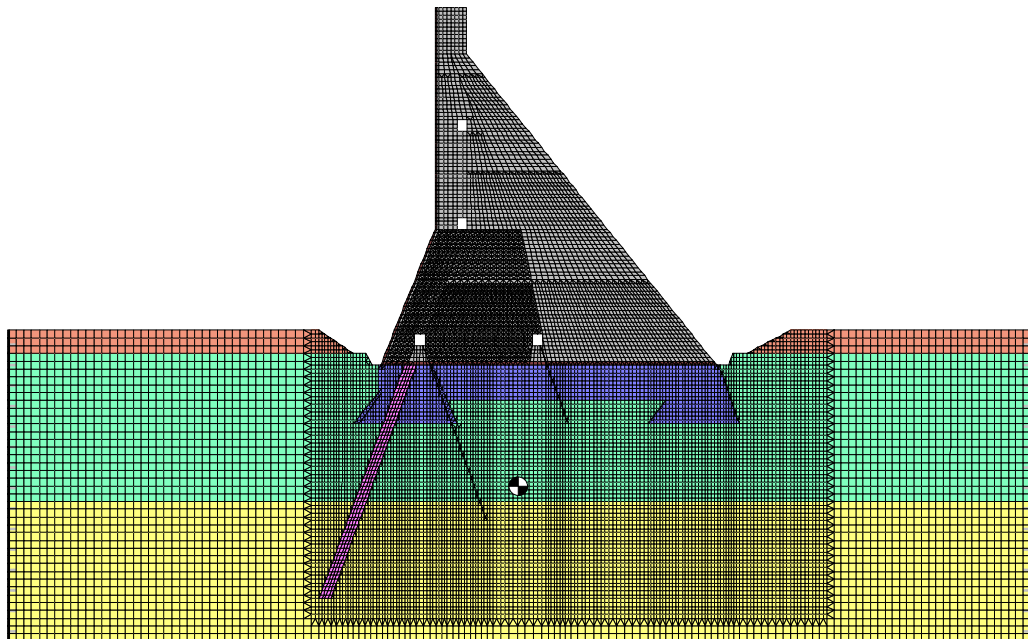


Figure 7. Mesh Generation for Dam Section Seepage Analysis

SEEPAGE MONITORING

Seepage Instruments

The seepage instrumentation was preliminary set up by the dam design's engineer and some modifications were done during the initial stage of construction. Table 3. shows the lists of instruments, typical location and their primary functions.

Table 1 Lists of instruments

<i>Instruments</i>	<i>Quantities</i>	<i>Item measured</i>	<i>Locations</i>	<i>Behavior evaluated</i>
1. Piezometers (Vibrating Wire)	106	uplift pressure, seepage pressure	dam foundation	effectiveness of grouting and drainage.
2. Observation wells	13	ground water seasonal change.	down stream area	Fluctuation of ground water level with time.
3. Seepage Flow Meters	80	seepage quantities	drainage gallery	seepage flow in foundation and dam body.

Table 4 RCC dam instrument schedules

Activities	y.2000	y.2001	y.2002	y.2003	y.2004	y.2005	y.2006
Construction		Construction Period					
Impounding						First Impounding	Second Impounding
Instrument Installation		Installation					
Reading			Reading				
Interpretation							Interpretation and Back Analysis

Vibrating wire piezometers with temporary switching units and portable reading unit are used during the construction. Then permanent data logger units are installed after completion of dam. The V-notch weirs are installed in the drain gutters in the galleries at elevation of +25.00, +55.00 and +80.00 m. MSL. The typical dam instruments sections are as shown on Figure 8 below.

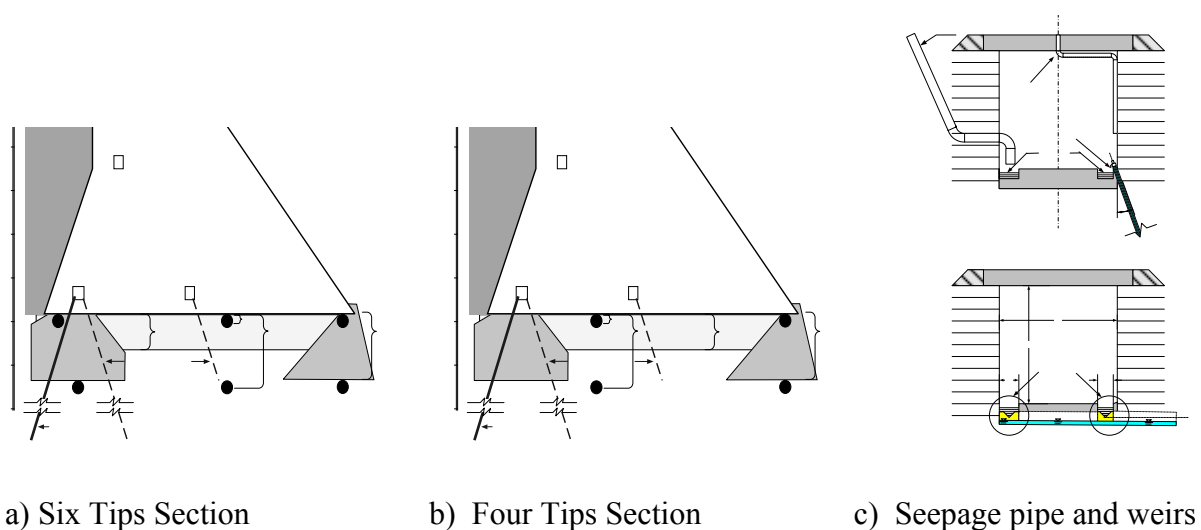


Fig. 8 Typical Piezometer and Seepage Weir Installations

RESULTS

Flownets

The flownets on dam body do not show any significant pattern since almost all of the leakage can collect into the gallery by the drain curtains on the upstream area. Then only the flownets in the dam foundation are emphasized on Figure The analysis shows that 70.8 and 23.3% of the total flow collected by the 1st and 2nd drainage curtains repectively. The remaining 5.8 % of foundation flow will go to the down stream area. This flow pattern indicated that for the normal case of grouting curtain and foundation drainage, the leakage to the down stream is limited and controllable.

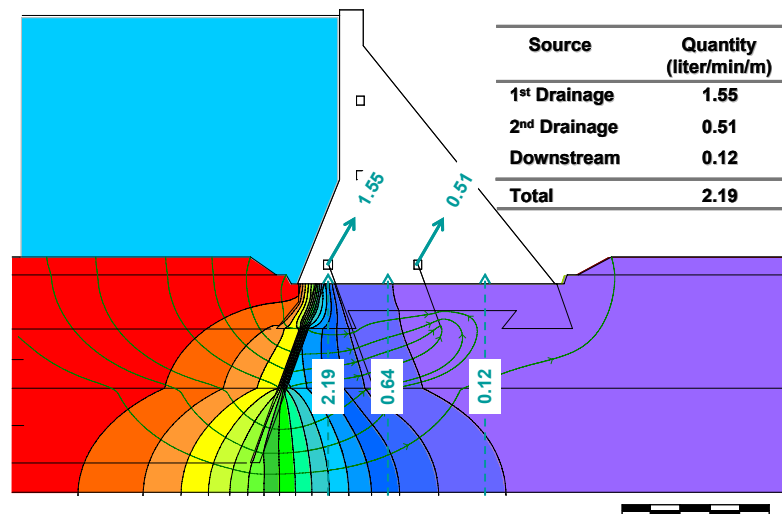
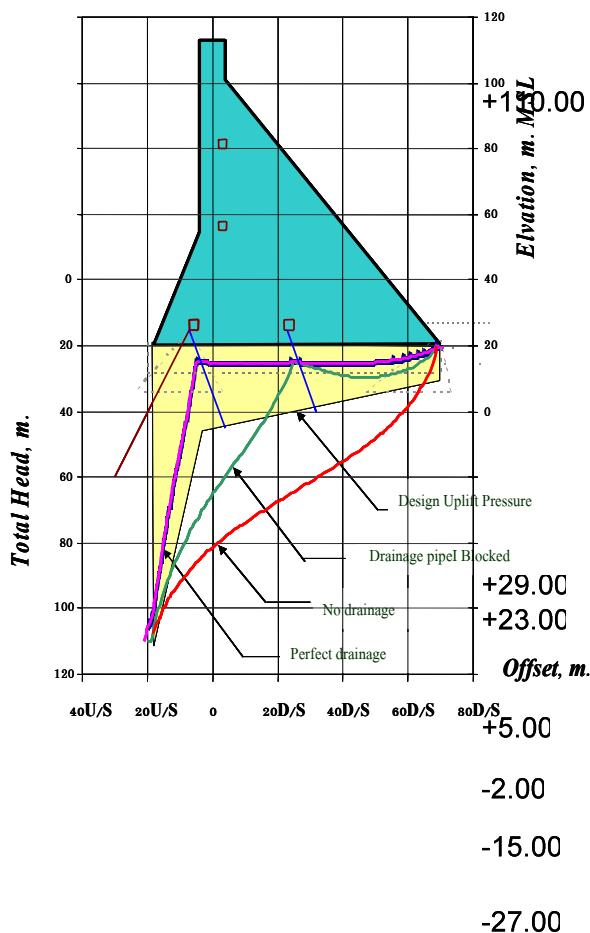


Figure Flownets in dam foundation



Uplift pressure under the dam foundation is important for the stability of the dam and also directly related to the effectiveness of the foundation drainages. The study shows on Figure... that uplift pressure is well below the design in the case of perfect foundation drainage. If the primary drain pipes are blocked, the secondary drain can still assist to lowering the uplift pressure. In case of both drainages are not effective at all, the uplift pressure will be well above the design. Thus during the dam operation, the uplift pressure observed from the foundation piezometers is very crucial. Cleaning of the drain holes by flashing from time to time can be a practical way to ensure the effectiveness of the drainage.

FigureUplift pressure distribution

Seepage Flows During Impounding

The seepage monitoring during first two years of impounding from April 2005 to February 2007 was performed. Seepage quantities on the flood plain foundation of both RCC-B and RCC-S are varied with reservoir water level as indicated on Figure..... In general, the average flow on second year is decreased to 50% from the first year. This tendency may come from many factors such as particles migration, rock joint filling, forming of filter cake surround drain pipes or accumulation of carbonate in the drain pipes. Further investigation should be done to confirm this behavior.

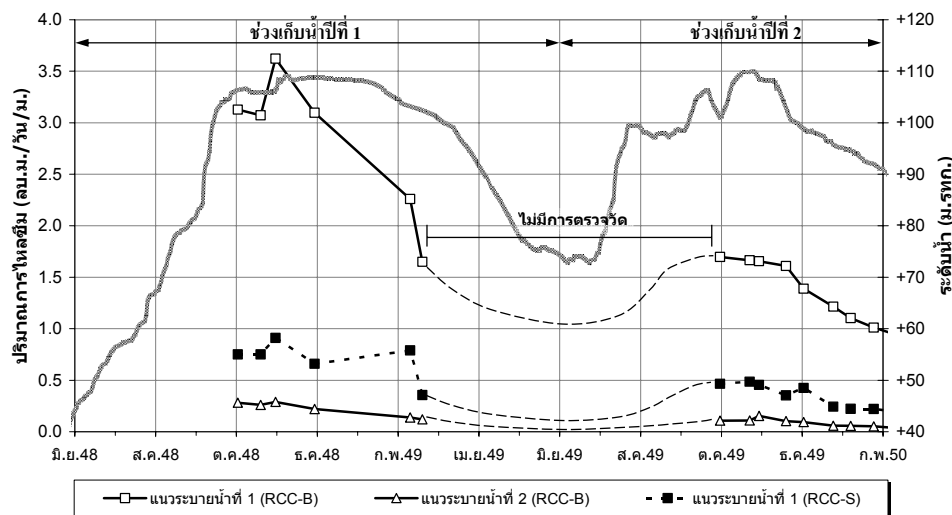


Figure Variation of flows per meter of dam during impounding

Table Seepage quantities during first two years of impounding

Flow (cu.m./day/m.)	Field Monitoring		Estimated by FEM (Thongtumachat. C., 2003)
	1 st Year	2 nd Year	
Primary drain curtain (Drain I)	3.62 (93%)*	1.66 (92%)	2.23 (75%)
Secondary drain curtain (Drain II)	0.29 (7%)	0.15 (8%)	0.73 (25%)

Remarks: figures in the parenthesis is the percentage of foundation flow collecting by drains.

Uplift Pressure

Field uplift pressures under dam foundation are observed during first two years to ensure the stability of the dam and foundation erosion. The foundation seepage area are divided into 3 zones; upstream zone, middle zone and downstream zone as shown on Figure The upstream zone represents the soil and rock foundation upstream of the curtain grouting with practically no seepage prevention. The middle zone are between grouting zone to first drainage curtain in which the pressure is expected to drop rapidly. And the downstream zone is covered from first drainage, second drainage to the dam downstream

area. Figure Shows the typical pressure responses of each seepage zone compared with the reservoir level. When reservoir water level reaches +80 m. MSL., piezometers P-1 start to response quickly toward the head ratio of 0.9 of reservoir water level. This behavior is elastic reversible, the pressure is decreased on the same path as the water drawback. The untreated rock joint opening under high water pressure is expected to occur at this state. The similar behavior on P-4 in the middle zone is also observed with the declined head ratio of 0.4. The pressure from the piezometers on the downstream zone had practically no response to the reservoir level. This is confirmed of the effectiveness of the drainage system.

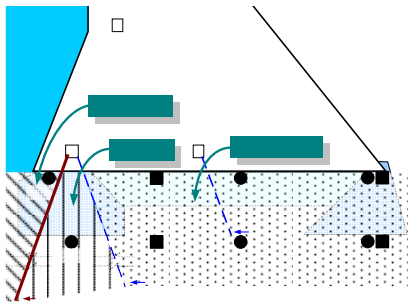


Figure Seepage zoning

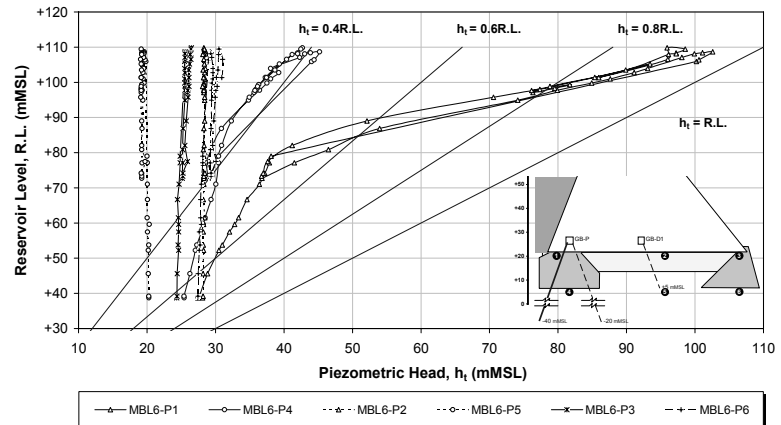


Figure Pressure responses from Impounding

By plotting of uplift pressure distribution under the dam foundation as shown on Figure.... can allow us to compare to the design pressure. And further more, the factor of safety against sliding and overturning of the dam can be checked on that particular condition. This is very important for dam safety evaluation during the dam operation.

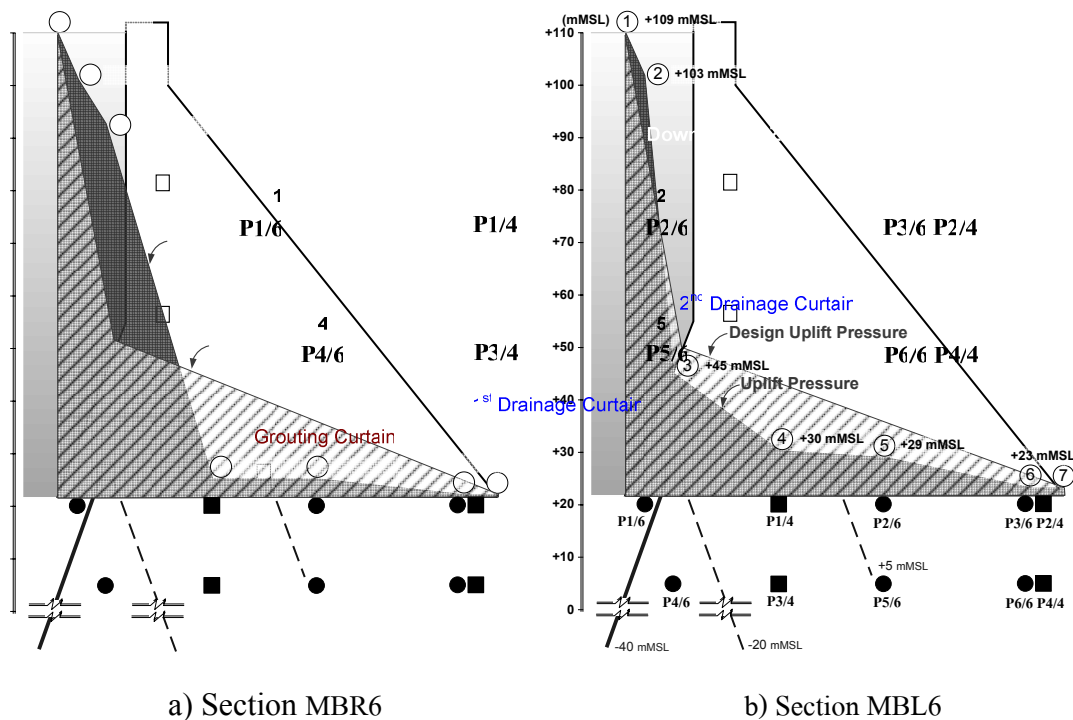


Figure Uplift Pressures in Dam Foundation

CONCLUSIONS

1. The King's initiated Khlong Tha Dan Dam is the first and largest RCC dam in Thailand under construction. The dam is 93 meters high, 2600 meter long and required RCC volume of 5.47 MCM. The seepage analyses and field monitoring of the dam are essential for the design and dam safety evaluation during operation.
2. Seepage analysis by FEM can be useful tool to prediction the seepage behavior of the dam in the design stage. And revised analysis is repeated according to the most recent data obtained during construction. The average seepage through the foundation is 2.19 liter/min/m. and 70.8, 23.3, and 5.8 % flow to primary drain, secondary drain and downstream area of the dam respectively. Predicted uplift pressure is well lower than the design assumption.
3. The results from field monitoring show the flow quantities decreased to 50% on second impounding year comparing to the first year.
4. Observed uplift pressures are generally less than the design. The pressure on the upstream area responses to the reservoir level distinctively when the reservoir is at +80.00 m.MSL. On the area of zone 2 and 3 downstream of grouting curtain, the pressure is well controlled by the foundation drainage system.
5. Measuring of uplift pressures from piezometers can allow for continuous calculating the factor of safety against sliding and overturning of the dam during operation.

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