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MONITORING THE LARGEST RCC DAM IN THAILAN D:KHONG THA DAN DAM

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ABSTRACT: Khlong Tha Dan 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. Thus the safety of the dam is very important and has to be carefully monitored by the extensive dam instruments. The dam instruments consist of 12 pendulums, 100 piezometers, 139 thermocouples, 100 jointmeters, 100 position targets, 100 leveling monuments and data processing equipment Pre-construction predictions such as stability, FEM stress-strain and thermal analyses were carried out during design stage. Since this dam is the first RCC Dam in Thailand, then its behaviors will be very important for the dam construction in future.

KEYWORDS: RCC DAM, DAM INSTRUMENTS, CONSTRUCTION BEHAVIORS

1. 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. King Bhumipol realized this potential hazardous situation well. On 1993, he initiated this project to Royal Irrigation Department(RID) for investigation the possibility to construction the dam. The purposes of the dam are for irrigation, flood protection, domestic and industrial water supply and leaching of acid 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. The project lay-out is shown on the Figure 1.

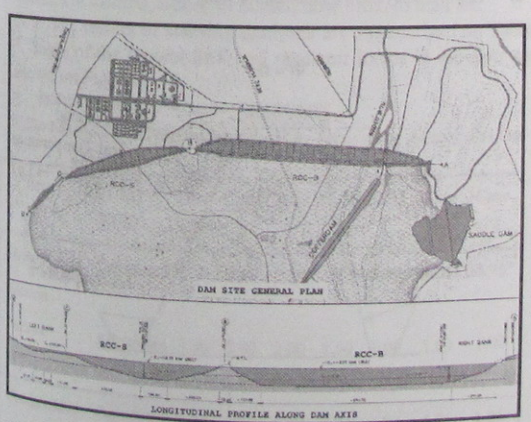


Fig. 1 Project layout

2. Dam features

The project consists of three dams as shown on Figure 1, the main RCC dam (RCC-B), the small RCC dam(RCC-S) and the 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	meters
Crest length	2,600	meters
Maximum width of foundation	78	meters
RCC dam volume	5.47million	cubic meters
Typical longitudinal RCC block	40	meters
Reservoir volume	224 million	cubic meters.

The dam section at spillway is shown on Figure 2.

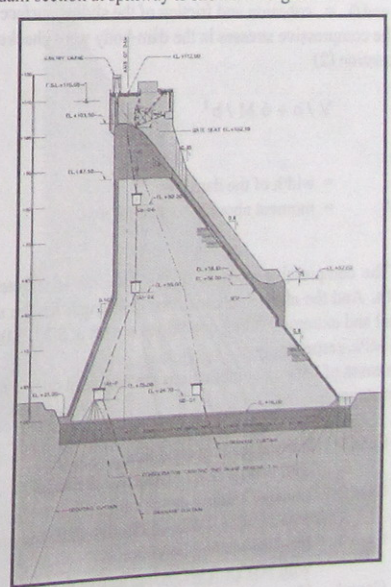


Fig. 2 Typical dam section

3. Geology of dam site

The project is located near the rim of the Korat Basin. Permo-Triassic Volcanic rocks is the main undifferential volcanic rocks over the entire project area including the dam site and reservoir. 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 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.

The RCC dam shall be designed for stability, stress-deformation, thermal stress during construction and expected serice period of the dam.

4. *Stability Analyses*

The purposes of stability analysis is to evaluate the resistance of the dam against sliding and overturning. The stresses in dam-body and its foundation rock are also can be checked under several loading conditions.

The sliding-stability criteria is depended on shear friction factor (SFF) which is defined on equation (1)

$$SFF = \frac{A.c + (V - U).\tan\phi}{H} \quad (1)$$

where

H = Σ horizontal forces
V = Σ vertical forces
U = uplift pressure,
A = area of dam sliding surface
c and ϕ = cohesion and friction of the sliding surface

The compressive stresses in the dam-body were checked by equation (2)

$$\sigma = V/b + 6.M/b^2 \quad (2)$$

where

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

The compressive strength of the concrete is targeted for 10 MPa. And the allowable compressive strength for the usual, unusual and extreme loading conditions are set at 3.33, 5.00 and 10.00 MPa. respectively.

Seven cases of loading combinations are analyzed during the design stages follows.

Case 1 Normal loading condition with NWL+ TWL Effective drainage

Case 2 Unusual loading condition I with MWL+ TWL + Effective drainage

Case 3 Unusual loading condition II with NWL+ TWL + Ineffective drainage

Case 4 Unusual loading condition III with NWL+ TWL + Effective drainage + No cohesion on horizontal construction joint and foundation contact

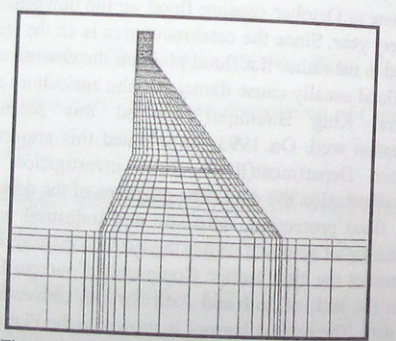
Case5 Extreme loading condition I with NWL+ TWL + Effective drainage + Earthquake forces

Case 6 Extreme loading condition II with MWL+ TWL + Ineffective drainage

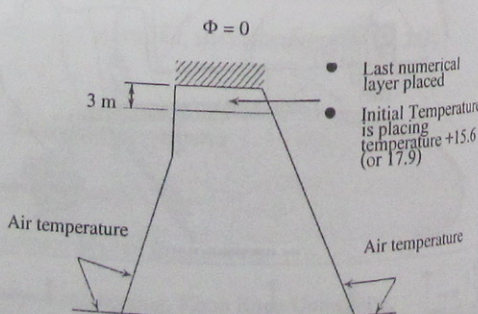
Case 7 Extreme loading condition III with MWL+ TWL + Ineffective drainage + No cohesion on horizontal construction joint and foundation contact

5. *Thermal Analysis*

Since RCC dam is a massive concrete structure, then the stresses created by temperature gradient should be controlled within the allowable limits. The heat from cement hydration is reduced by partial replacement of cement by flyash. Then during construction, the dam should be checked and controlled for the excessive temperature gradient to prevent the tension crack due to expansion and contraction of concrete. Thermal analysis is the computation of temperature patterns inside the dam with the corresponding thermal stresses due to the temperature gradients. The finite element method (FEM) is applied for both temperature pattern and thermal stress calculations. Two dimensional finite element mesh and the Boundary condition are shown on Figure 3.



a) Thermal analysis two dimensional analysis



b) Thermal analysis two dimensional analysis calculation methodology

Fig. 3 Finite element mesh and boundary conditions fot

6. Stress and Deformation Analyses

Three geological conditions of foundation rocks namely; volcanic tuff, rhyolite and andesite are considered in stress-deformation analyses. The stress-strain FEM stress-strain analyses was employed. Results will be used for checking of differential settlement between each 40 meters dam section and also tilting of the dam crest. While the stresses distribution can indicate the potential of stress concentration and cracking. In order to cover all the possible natural conditions, the calculations were carried out according to the following cases.

Case 1. Homogeneous foundation of E_s = 10,000 MPa (Highly jointed fractured zone)

Case 2. Heterogeneous foundation of E_s = 20,000 MPa (Massive Rhyolite/Andesite zone) for the first 25 meters and E_s = 10,000 MPa for the lower foundation.

Case 3. Heterogeneous foundation of E_s = 20,000 MPa (Massive Rhyolite/Andesite zone) for the first 75 meters and E_s = 10,000 MPa for the lower foundation.

Case 4. Homogeneous foundation of E_s = 20,000 MPa (Massive Rhyolite/Andesite zone)

Case 5. Heterogeneous foundation of E_s = 10,000 MPa (Highly jointed fractured zone) for the first 25 meters and E_s = 20,000 MPa for the lower foundation.

Case 6. Heterogeneous foundation of E_s = 10,000 MPa (Highly jointed fractured zone) for the first 75 meters and E_s = 20,000 MPa for the lower foundation

Young's Modulus of the RCC dam-body is assigned as 20,000 MPa.

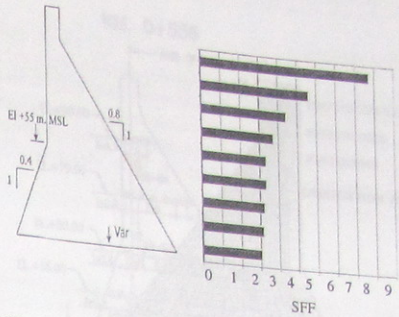
The primary consideration of dam monitoring is to obtain necessarily data for dam safety evaluation. And the secondary importance is obtaining information to check initial assumptions in order to modify the design and construction for the future dams.

The predicted behaviors of RCC dam during construction and beginning of the service periods are important guide lines for monitoring program. This informations will help the design engineer to select what behaviors to be monitored, what kind of instrument needed, where to install, how often to read etc.

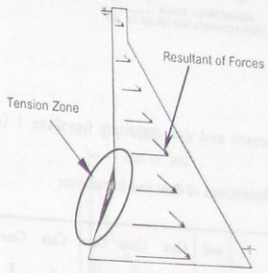
The results of stability analyses are summarized on Table 1. Some of the typical SFF and resultant forces in the dam are shown on Figure 4.

Table 1 Summary of Results from Stability Analysis of Khlong Tha Dan

Items		*Case 1*	*Case 2*	*Case 3*	*Case 4*	*Case 5*	*Case 6*	*Case 7*
Shear Friction Factors (SFF)	Calculated	3.04	3.00	2.55	1.78	2.79	2.51	1.76
	Allowable	3.00	2.00	2.00	1.50	1.00	1.00	1.00
Compressive Strength (σ)MPa.	Calculated	1.24	1.26	1.20	1.24	1.34	1.22	1.25
	Allowable	3.33	5.00	5.00	5.00	10.00	10.00	10.00



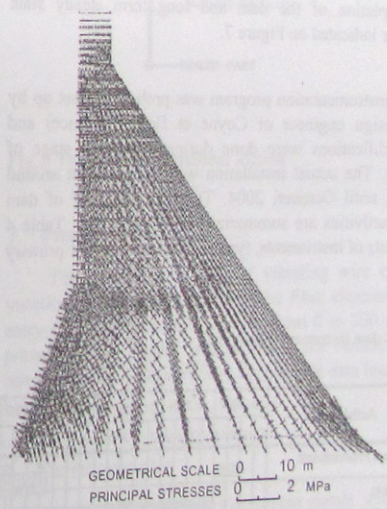
a) Shear Friction Factors (SFF) vs. Elevation for Case 1



b) Locations of the resultant forces and cracking area Case 6

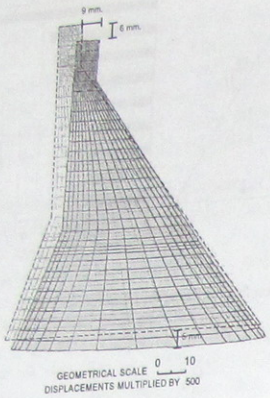
Fig. 4 Results of stability analyses of RCC dam

The stresses and deformations of the dam-body and it's foundation are summarized on Table 2 shown below. The typical stresses and deformations for Case 1 are as shown on Figure 5.



a) Orientation of principal stresses

Fig. 5 Results of stresses and deformations for Case 1



b) Deformation

Fig. 5 Results of stresses and deformations for Case 1 (cont")

Table 2 Stresses and deformations of dam and foundation

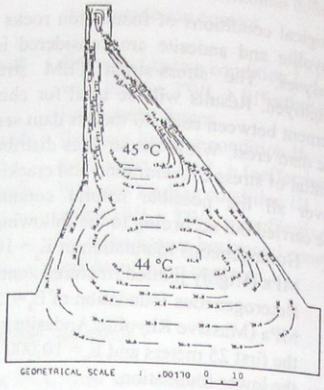
Quantities	*unit*	*Case 1*	*Case 2*	*Case 3*	*Case 4*	*Case 5*	*Case 6*
Principal stress at foundation	MPa.	1.50	1.90	1.70	1.80	1.60	1.60
Crest vertical deformation	cm.	1.25	1.05	1.00	0.90	1.10	1.20
Crest horizontal displacement	cm.	1.00	0.95	0.80	0.60	0.70	0.90
Foundation vertical deformation	cm.	0.95	0.80	0.60	0.50	0.60	0.80

The temperature contours from thermal analyses are as shown on Figure 6. While the corresponding thermal stresses during completion of the dam and long term steady state condition are indicated on Figure 7.

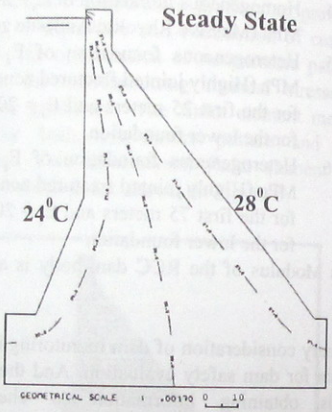
The instrumentation program was preliminary set up by the dam design engineer of Coyne et Bellier (France) and slightly modifications were done during the initial stage of construction. The actual installation will be started at around April, 2001 until October, 2004. Tentative schedule of dam instrument activities are summarized in Table 3 and Table 4 shows the lists of instruments, typical location and their primary functions.

Table 4 RCC dam instrument schedules

No.	Activities	yr. 2000	yr. 2001	yr. 2002	yr. 2003	yr. 2004
		Q3 Q4	Q1 Q2 Q3 Q4	Q1 Q2 Q3 Q4	Q1 Q2 Q3 Q4	Q1 Q2 Q3 Q4
1	Instrument Procurement					
2	Installation					FINAL
3	Data Reading and Processing					
4	Training for RID's personals			1	2	3

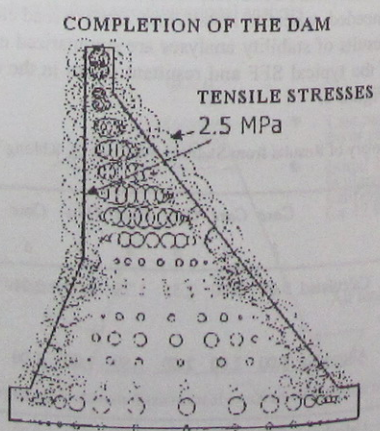


a) During construction



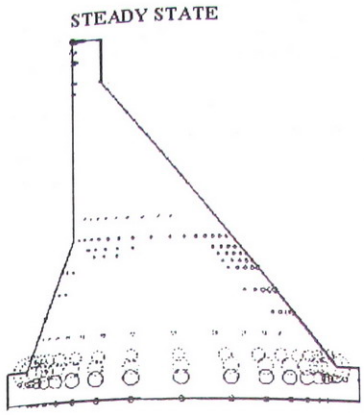
b) During reservoir storage

Fig. 6 Results of temperature patterns



a) Drawing construction

Fig. 7 Results of thermal stresses



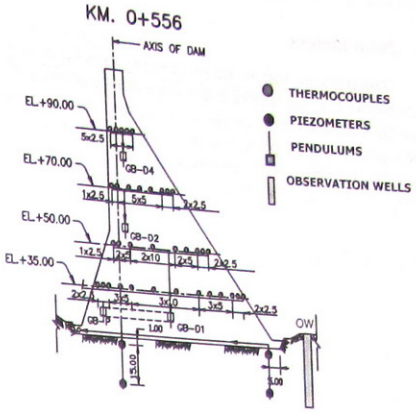
b) During reservoir storage

Fig. 7 Results of thermal stresses (cont')

Table 4 Lists of instruments

Instrumentsq	*QTY*	*Item measured*	*Locations*	Behavior evaluated
1. Piezometers (Vibrating Wire)	100	uplift pressure	Dam foundation	effectiveness of grouting and drainage.
2. Thermocouples	139	Temperature	Dam body	temperature pattern during construction and impounding.
3. Joint meters	100	relative movements	dam body, between RCC blocks	relative triaxial movements between the construction joints.
4. Position survey targets	100	horizontal movement	dam crest	horizontal movement during impounding and drawdown
5. Levelling survey monuments	100	vertical movement	dam crest	vertical movement during impounding and drawdown
6. Pendulums	12	tilting, sway	dam body, dam foundation	tilting and sliding of dam related to foundation rock.

The typical dam instruments sections are as shown on Figure 8 below.



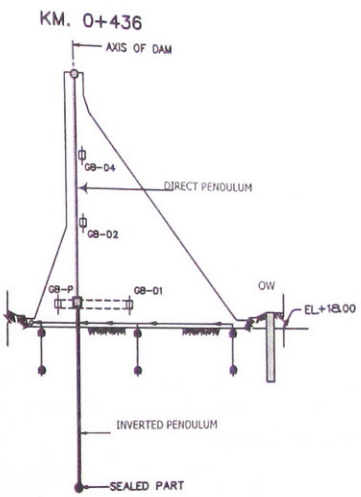


Fig. 8 Typical dam instrument section

7. Piezometers

The electric piezometer of vibrating wire type will be installed in the dam foundation. The filter element is high air entry suitable to measure pressure from 0 to 200 m. of water pressure. All of cables will be led to the switching terminal boxes in the dam gallery where the portable data logger unit can be connected.

8. Thermocouples

The heavy duty Copper-Constantan metals with measuring range of -10 to 105 ^{0}C will be adopted. Installation shall be done during the compaction of RCC dam at predefined locations. The readings will be taken at the junction box in the gallery.

9. Joint meters

Triaxial joint meters are proposed to monitor the relative movements between the adjacent 40 meter long RCC blocks. Two arms are fixed to each block across the construction joint. The digital dial gage plunger will be fitted to the hemispherical anvil to measure the movement in each direction. The configuration of joint meter is shown on Figure 9.

10. Pendulums

Total 12 direct and inverted pendulums will be installed to measure the horizontal displacements of dam and foundation. The fittings are as shown on Figure 10. below. The change of x-y coordinates of hanging rod indicate the tilting and sliding of the dam body. The movements can be detected by direct measurement by optical microscope or automatically detector by infra-red beam.

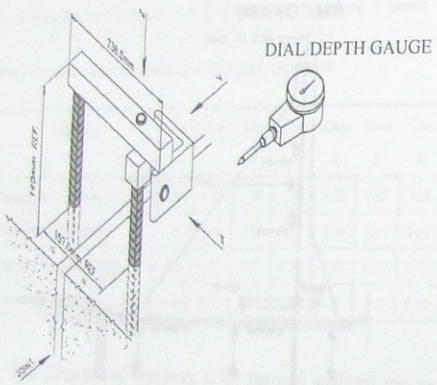


Fig. 9 Installation of joint meter

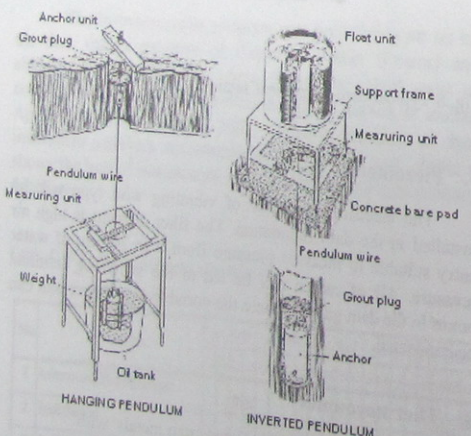


Fig. 10 Direct and inverted pendulums

Conclusions

1. The King's initiated Khlong Tha Dan Dam is the largest RCC dam in Thailand under construction. The dam is 93 meters high, 2600 meter long and required RCC volume of 5.47 MCM. At the present, this dam is considered to be the world largest RCC dam

2. It is situated just upstream of city of Nakorn Nayok, the tourist and famous fruit plantation area. Thus the safety of the dam and people in the vicinity is very important. The extensive dam instrumentation program was planned for monitoring the behaviors of the dam during construction and reservoir impounding.

3. The geology of the dam site is on the undifferential volcanic rocks, mainly rhydolite, andesite, tuff, agglomerates and breccia. Generally, the rock mass is in good condition according to RMR classification system.

4. Prediction of the dam behaviors were carried out during the design stage. First, the stability analysis was performed to ensure the safety against sliding, overturning, and compressive stress at dam foundation . Second, the thermal analysis of temperature pattern and tensile stress due to temperature change was calculated. And finally, the stress-deformation FEM analyses was done to predict the stresses and deformation of dam and its' foundation.

5. Six types of dam instruments are planned to install for dam monitoring during construction and reservoir impounding. There are 100 piezometers, 139 thermocouples, 100 joint meters, 100 position targets, 100 leveling targets and 12 pendulums. The readings will be done mainly by automatic read-out unit via data logger and processing by the computer.

6. The results from dam monitoring are relevant for judgment of the dam safety and also contribute to the design and construction of the future RCC dam in Thailand.

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