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Major slope stability problems in dam constructions in Thailand

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ABSTRACT: During dam constructions in Thailand, several slope failures occurred and various expensive remedial measures for slope stabilizations and slope protections were employed. It is accepted that geology plays a leading and very important role in analyzing slope stability problems. Yet, a large sum of extra money were used in stabilizing slopes of dams which include slopes of powerhouse, slopes of switchyard, and slopes of spillways. This paper summarizes the causes and remedial measures of slope stability problems of four hydro dams. Geological information, in reality, can not be fully obtained. However, this paper shows that more attention should be paid to geological investigation budget. No matter how hard we try to obtain geological data for slope design, it is rather impossible to guarantee that one's design is perfect without extra cost of additional remedial measures of slope.

1 INTRODUCTION

After the completion of the first hydro dam, Bhumibol dam, in Thailand in 1963. Within 25 years, the Electricity Generating Authority of Thailand, EGAT, has constructed 12 more hydro dams, both large and small, here and there all over the country to cope with the ever-increasing demand of electric power of Thailand.

Nowadays, slope designs are more practical and less time consuming by the application of computers. In this study, the limiting equilibrium technique, together with microcomputer application, are applied to evaluate the stability condition of rock cut slopes of four major hydro dams in Thailand, namely, Chiew Larn Dam, Bang Lang Dam, Khao Laem Dam, and Srinagarind Dam. Their locations are presented in Fig.1.

2 SLOPE FAILURES DURING CONSTRUCTION OF FOUR MAJOR HYDRO DAMS

(1) Chiew Larn Dam

The slope stability problems occurred at so many places during construction. These can be described place by place as follows:

(a) Powerhouse slope or penstock slope.
Rocks that have been cut to the gradient vary from 1:1 to 0.2:1 (horizontal distance to vertical distance) are mainly pebbly mudstone and some shale. There are reports of some plane failures occurred along the bedding plane of those rocks which generally daylight on the slope face, dipping 40-45 degrees. Consequently, two units of three multiple points extensometers have been installed to detect the movement of slope. After plane failure occurred, the slope was re-excavated to the gradient varying from 1:1 to 1:0.5. In addition, to stabilize the slope, 60 tons prestressed tendon, rock bolts, shotcrete, drain hole and chain link fabric were also installed.

(b) Flip bucket slope
Flip bucket locates on the downstream portion of the spillway structure. The rock type in this area comprises mainly of pebbly mudstone, shale, sandstone and some shallow intrusive jointed igneous rock. The fractures and minor faults have been discovered considerable, so the rock condition was fair to poor with some fractures favorable to the slope failure. From stability analysis, plan failure was likely to occur. Consequently, 60 tons prestressed tendon including, rock bolts have been installed to protect the slope.

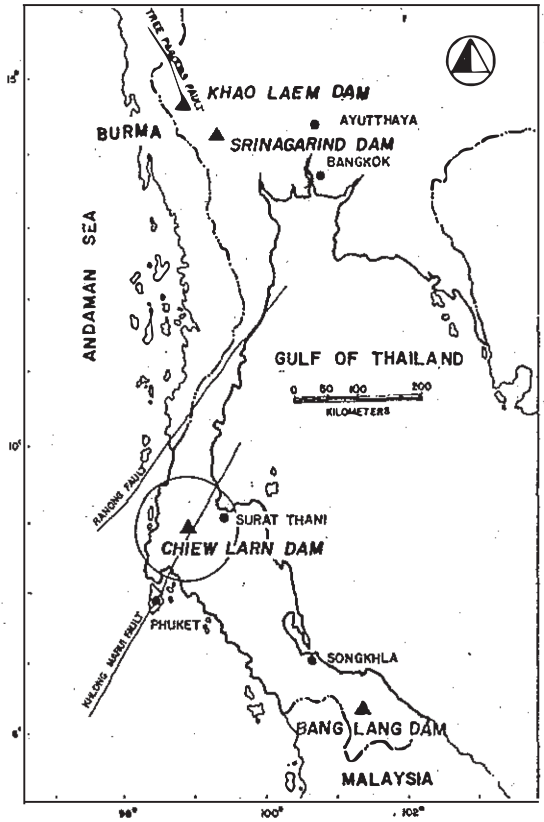

Fig. 1 Locations of hydro dams.

(c) Spillway slopes
The rocks in this area are mainly pebbly mudstone and shale. The rocks that have been excavated from the spillway channel are also used as the rock fill material for the main dam and the saddle dam. The gradient of the spillway slope is of 0.5: 1 (h:v). During excavation, plane and wedge failure occurred at many places. Since the failed slopes do not influence important structures, the slope stabilization is not necessary.

(2) Bang Lang Dam
Rocks dominantly comprise of sandstone, shale, mudstone and some metamorphic rocks which are subjected to high weathering. Slope failure occurred at many places especially where highly weathered rocks have been found. During construction period, circular failures generally occurred after heavy rainfall at the residential area, some 1-1.5 km south of the damsite.

(3) Khao Laem Dam
During construction, the rock cut slopes of some appurtenance structures have been reported of slope failure which can be described separately as follows:

(a) Diversion channel (See Fig.2)
The diversion channel was excavated across the Three Pagoda Fault which the rocks comprise mainly of thin bedded black shale, siltstone and some sandstone: From design criteria, the slope gradient varies from 0.5:1 to 1:1 (h:v) regardless the geological conditions. Some small wedge and plane failures occurred especially where the black shale exposed. Consequently, the slope was re-excavated which the gradient varied from 1.5:1 to 2.1 from the bottom to the top of slope.

(b) Left abutment (See Fig.3)
During excavation of left abutment slope, single point extensometers revealed the movement of slope along the clay seam 10 cm thick which daylighted at elevation 207.0 m (MSL). The result of direct shear test revealed the cohesion and friction angle of clay seam about 8-10 t/sq.m and 25-30° respectively. From stability analysis after HOEK & BRAY (1981), stabilization of slope was extremely necessary. Hence, 91 sets of 70 tons strand anchors have been installed to stop the movement.

(c) Right abutment
The right abutment of Khao Laem Dam lies on Ratburi Limestone or Khao Laem Massif where the highly-steep fault scarp exists. There have been reports on small toppling and rock falls during construction but no effect to the dam structure. On December 16, 1981, 10000 tons of limestone fell down some 50 m. upstream. Consequently, rock bolts and shotcrete have been performed to stabilize the slope.

(4) Srinagarind Dam
Stability problem of rock cut slopes occurred during the excavation of penstock slope and spillway slope. LEK KANCHANAPOL (1978) stated that slope failure occurred at the penstock slope was due to the bed condition of shaly limestone, quartzite which exposed in between two adjacent faults. According to the wide sheared zone in between those faults, circular mode of failure was likely to occur. From circular failure analysis, the factor of safety of the slope was 0.60. After stabilization by rock bolt, strand anchor, the Factor of Safety was 1.69 and considered to be safe for the long period of time.

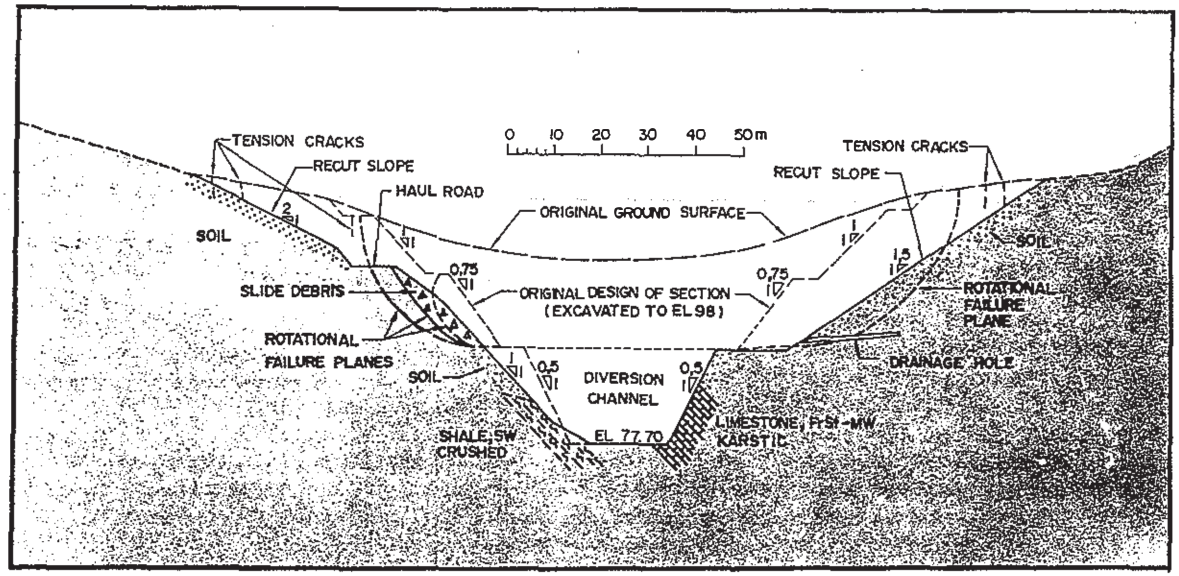

Fig. 2 A case study of slope design failure at the diversion channel of Khao Laem Dam, Western Thailand.

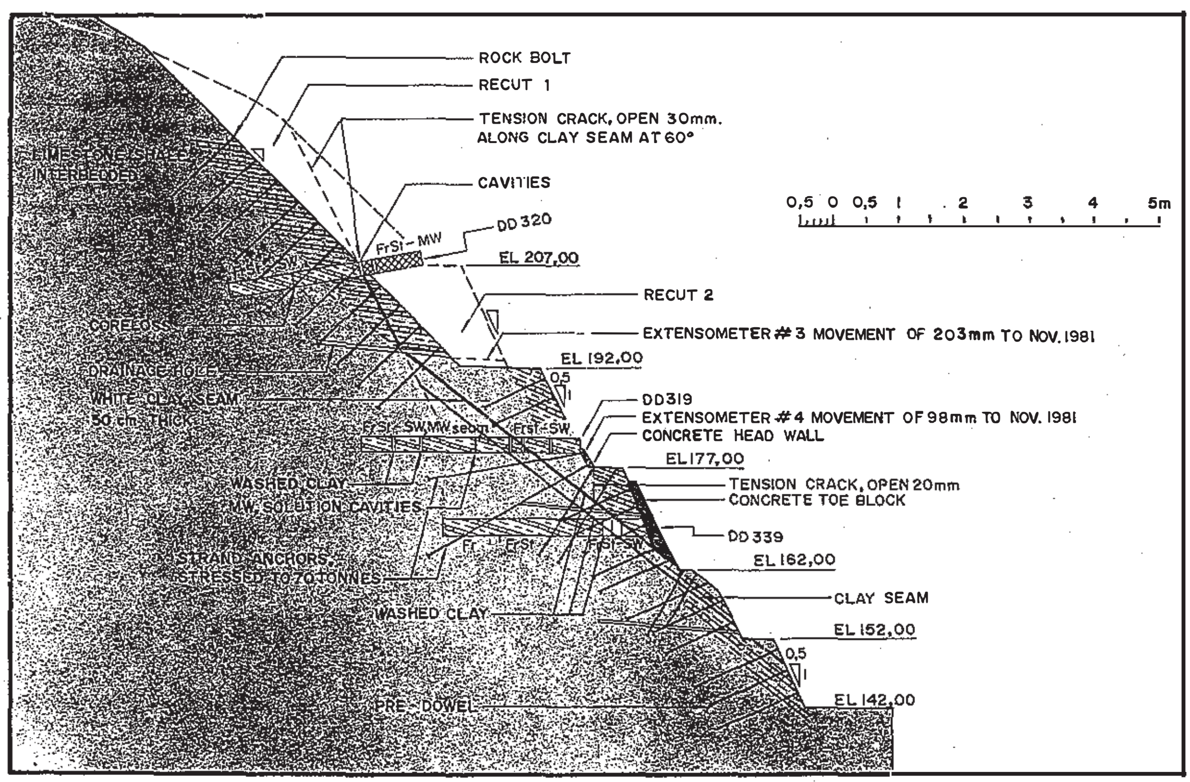

Fig. 3 A case study of spillway crest excavation and support system of Khao Laem Dam, Western Thailand.

Table 1. Results of Plane Failure Analysis (HOEK & BRAY Method and HENDRON Method)

DAM	SLOPE LOCATION	UNIT OF SLOPE	SLOPE HEIGHT (M.)	DIP OF SLOPE FACE	DIP OF FAILURE PLANE	UNIT WEIG. OF ROCK (T/CU.M.)	UNIT WEIG. OF WATER (T/CU.M.)	SEISMIC ACC. (g)	COHESION (C) (T/SQ.M.)	FRICTION ANGLE (DEGREE)	BOLTS&CABLES TENSION (T/M.)	BOLTS ANGLE (DEGREE)	F OF S AFTER HOEK &BRAY: DRY NO BOLT	SATURATED NO BOLT	DRY BOLTED	SATURATED BOLTED	F OF S AFTER HENDRON: DRY NO BOLT	SATURATED NO BOLT	DRY WITH BOLT	SATURATED WITH BOLT
1) CHIEW LARN	:SPILLWAY	1 BENCH SYSTEM SP1	15.0	63.4	44.0	2.63	1.00	0.00	0.0	45.0	-	-	1.04	0.53	-	-	-	-	-	-
		2 OVERALL SLOPE SP1	44.0	55.0	44.0	2.63	1.00	0.00	0.0	45.0	-	-	1.04	0.59	-	-	0.97	0.58	-	-
		3 BENCH SYSTEM SP7	20.0	63.4	52.0	2.63	1.00	0.00	0.0	45.0	-	-	0.78	0.31	-	-	-	-	-	-
		4 OVERALL SLOPE SP7	30.0	57.0	52.0	2.63	1.00	0.00	0.0	45.0	-	-	0.78	0.36	-	-	0.75	0.36	-	-
		5 BENCH SYSTEM SP8	15.0	63.4	38.0	2.63	1.00	0.00	0.0	45.0	-	-	1.28	0.72	-	-	-	-	-	-
		6 OVERALL SLOPE SP8	26.5	54.0	38.0	2.63	1.00	0.00	0.0	45.0	-	-	1.28	0.79	-	-	1.23	0.87	-	-
		7 BENCH SYSTEM SP10	15.0	63.4	56.0	2.63	1.00	0.00	0.0	45.0	-	-	0.67	0.21	-	-	-	-	-	-
		8 OVERALL SLOPE SP10	32.0	54.0	56.0	2.63	1.00	0.00	0.0	45.0	-	-	0.67	0.28	-	-	0.67	0.27	-	-
		9 FLIP BUCKET	14.0	63.4	53.0	2.63	1.00	0.15	3.0	35.0	13,7,11.5	45,6,11	1.20	0.66	2.05	1.60	0.54	0.27	1.26	0.96
	:POWERHOUSE	BERM NO. 1	11.0	65.0	40.0	2.63	1.00	0.00	8.3	37.0	12.225	50.0	2.45	1.68	3.06	2.31	0.96	0.63	1.34	0.93
		BERM NO. 2	10.0	65.0	36.0	2.63	1.00	0.00	8.3	37.0	4.95	50.0	2.62	1.98	2.88	2.16	1.15	0.83	1.34	1.07
		BERM NO. 3	13.7	45.0	42.0	2.63	1.00	0.00	8.3	37.0	-	-	3.00	2.50	-	-	0.81	0.48	-	-
		OVERALL SLOPE FACE	34.7	45.0	40.0	2.63	1.00	0.00	8.3	37.0	17.17	50.0	3.10	2.75	3.38	3.00	1.00	0.68	1.15	0.90
2) BANG LANG	:LEFT ABUTMENT	-	20.0	53.0	35.0	2.65	1.0	0.00	3.0	27.0	-	-	1.17	0.88	-	-	0.73	0.53	-	-
3) KHAO LAEM	:LEFT ABUTMENT	-	43.0	55.0	35.5	2.65	1.0	0.00	6.0	25.0	78,80	25,45	1.16	0.86	1.38	1.05	0.61	0.44	0.78	0.60

3 MAJOR SLOPE PROBLEMS AND MODES OF OCCURRENCES OF SOIL & ROCK SLOPES

In Thailand, several major slope problems occur on both natural and cut slopes in dam construction as following;

1 Chiew Larn Dam;
Plane failure of Penstock Slope

Table 2. Summary of Stability Analysis of Slopes

Dam	Slope Location	Unit of Slope	Mode of Failure	Factor of Safety
1. Chiew Larn	Spillway	sp1	Plane	1.04
		sp2	Wedge	1.32
		sp5	Wedge	1.15
		sp7	Plane	0.78
		sp8	Plane	1.28
		sp10	Plane	0.67
		Flip Bucket	Plane	2.05
	Powerhouse	Berm 1	Plane	3.06
		Berm 2	Plane	2.88
		Berm 3	Plane	3.00
		Overall Slope	Plane	3.38
2. Bang Lang	Powerhouse		Circular	1.17
	Left Abutment		Plane	1.17
	Right Abutment		Circular	1.40
3. Khao Laem	Left Abutment		Plane	1.38

2 Bang Lang Dam;
Circular slope failure at power house and residential area.

3 Khao Laem Dam;
Plane failure on the left abutment of rock slope.

4 Srinagarind Dam;
Plane failure on penstock slope.

In general, the common modes of slope failure is plane failure in rock excavation and the cause of failure is unanticipated geology conditions, construction technique of excavation (uncontrolled blasting). Plane failure usually occurs in both small and large scale failures while wedge failure normally occurs as small scale failure. Toppling failure is not common. Circular failure both small and large scale, is found in soil and highly weathered and heavily fractured rock slopes.

4 REMEDIAL MEASURES REQUIRE FOR CRITICAL SLOPES

Remedial measures required for critical slope depend on the factor of safety and the risk to life and/or structured recommended by Geotechnical Control Office, Public Work Department, HONG KONG (1979).

According to the analysis of existing slopes in terms of the factor of safety as shown in Table 1, summary of areas and their factors of safety can then be finalized as shown in Table 2.

Table 3. Summary of Additional Cost of Stabilization Works due to Slope Problem of Chiew Larn Dam

Location	Description	Unit	Quantity	Thai Currency	Total Amount (baht)
Powerhouse Slope	- Rock bolts resin anchor Tendon 60 ton 20 m.long Shotcrete Grouting Recut slope Multipoints extensometers			Subtotal	= 3625534.61
Flip Bucket Slope	- Tendon 60 ton	m.	308.00	1992.82	613788.56
	- Rock bolts	m.	750.00	273.39	205042.50
	- Anchor bars	m.	91.00	133.05	12107.55
	- Material	kg.	895.20	3.45	3088.49
				Subtotal	= 834027.05
				Total	= 4459561.66

Table 4. Summary of Additional Cost of Stabilization Works due to Slope Problem of Khao Laem Dam

Location	Description	Unit	Quantity	Total Thai Currency	Amount bath
Left	- Extensometer	LS	1.00	6000.00	6000.00
Abutment	- Dywidag rock anchor	m.	738.00	1200.00	885600.00
	- Rock bolts	m.	24873.00	906.00	22534938.00
	- Anchor bars	m.	21946.00	363.00	7966398.00
	- VSL rock anchors	m.	2156.00	3475.00	7492100.00
	- Anchor bolts	m.	86285.00	35.00	3019975.00
	- Dywidag washers	LS	1.00	49442.00	49442.00
	- Crane time to install rock bolts	hr.	299.00	780.00	233220.00
	- Materials	LS	1.00	382000.00	382000.00
				Total =	42569673.00

5 ADDITIONAL COST DUE TO CRITICAL SLOPES

Examples of addition costs due to critical slopes of Chiew Larn and Khao Laem dam are shown in Table 3 and Table 4 respectively. For penstock slope of Srinagarind dam, the total cost incurred for the protection of the rock sliding was totally US$ 1.14 million.

6 CONCLUSIONS

From data and tables obtained from several case studies of dam construction in Thailand as shown in this paper, it can be said that, in practical, dam constructions cannot avoid slope excavations especially rock slope stability problems.

Plane failures in dam constructions usually occur with a large rock mass and always very costly to treat while wedge failures occur here and there but of no vital hazards for dam construction. From several case studies during dam constructions, it has also been convinced that geological information obtained during investigation period were insufficient and caused delays which has many chain effect on construction schedule.

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