DAM SAFETY EVALUATION BY CONDITION INDEX SYSTEM

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ABSTRACT: Thailand has nearly 5000 dams which some of them almost 50 year old. Electricity Generating Authority of Thailand (EGAT) and Royal Irrigation Department (RID) are only two government organizations who have dam safety sections. Although dam failures in Thailand were happened to small dams and did not cause a lot of damage to lifes and properties. But several dam owners are now seriously considering the dam safety program. The "Condition Index System" originated by US. Corps of Engineers are adopted for dam safety and maintenance evaluation and maintenance program for RID-Regional Office No.9. The process consists of dam inventory, field inspection and dam condition evaluation in the dam data base. Finally, the recommendations for repair and rehabilitation can be done systematically. The interaction matrices are used to formulate the relative weights among dam components. The condition indices (C.I.) of 32 dams on eastern region are ranging between 69.33 to 83.83. There are the significant relations between CI with size and age of dams.

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KEYWORDS: Dam Safety, Condition Index System

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1. INTRODUCTION

Storage dam had been build in Thailand for some seven hundred years ago during Sukhothai period for King Phra Narai's royal palace water supply. The end of the Second World War marked the beginning of modern dam building in Thailand. During the past 50 years, almost 5000 dams have been constructed by several government agencies, mostly for hydropower generation, irrigation, industrial and domestic uses. Although the dam failure and incidents were happened from time to time mostly involved small dam with inadequate spillway and seepage protection. However, not all dam failures had been recorded. And the damage to properties, crops and loss of life sometime is not fully known. The Electricity Generating Authority of Thailand (EGAT) who owns 30 large dams started their dam safety program in 1982.The Royal Irrigation Department (RID) who responsible for more then 4000 dams realized the important of dam safety and established the Dam Safety Inspection and Evaluation Center in 1992. After the incident of Upper Mun Dam leakage, Thai Government orders to inspect 225 large dams all over the country. Later in 1996, RID. started their "Dam Safety Project" with the supports by the World Bank for 25 year program. Unfortunately after some project preparation works and reassessment of spillway capacity and remedial design of two selected dams had been done, the project was slowed down by economic resession in Thailand, In parallel, RID Regional Office No.9 initiates the Dam Data Base Project for Dam Safety Evaluation and Maintenance with Kasetsart University. On this project, the data of 32 dams including extensive field inspection, drawings, construction control, dam monitoring, past remedial works, operation and management etc. were collected in the data base. Then using Condition Index System (CI), the gradings of each dam were evaluated according to their dam safety, maintenance, repairing and rehabilitation conditions.

2. DAM SAFETY PROGRAM IN THAILAND

Dam Failures

The total number of dams in the world may exceed 150,000 dams at the present. There have been about 200 notable dam failures in the world so far in the 20th century. And more than 8000 peoples lost their lives in these disasters. (USBR, 1983) as shown on Table 1.

Dam failures in Thailand were generally occurred on the small dams with inadequate spillway capacity, leakage in foundation and erosion on dispersive soil as shown on Table 2.

Table 1 Lives Lost by some of the Major Dam Failures

Dam	Country	Year Failure	Lives Lost
Machhu II	India	1979	2000^{+}
Dam Ildefonso	Bolivia	1626	~4000
Vaiont	Italy	1963	2600
South Fork	USA	1889	2209
Panshet-Khadakwasla	India	1961	Unknown
Oros	Brazil	1960	~1000
Puentes	Spain	1802	608
Kuala Lumpur	Malaysia	1961	600
Gleno	Italy	1928	600

Source : Dams and Public Safety, USBR. (1983)

Table 2 Known Dams Incidents in Thailand

YEAR (A.D.)	DAM NAME	LOCATION	OWNER	CAUSES	CONSEQUENCES
Between 1970 to 1972	Lum Sumlai Lum Chiengkrai Umpuen Huai Sawai	Nakorn Ratchasima Nakorn Ratchasima Surin Burirum	RID RID RID RID	dispersive clay on dam embankment	- damaged sections were rebuilt
1978	Ubolratana	Khon Kaen	EGAT	Large inflow from heavy rain	- nearly overtopped - d/s areas were flooded due to spilled water - dam crest was raised - spillway was enlarged
1983	Huai Takien	Prachinburi	RID	Internal cracking and dispersive clay	- damaged section was rebuilt
1990	Upper Mun	Nakorn Ratchasima	RID	Foundation leakage Problem	- leakage through foundation - evacuation of d/s villagers - dam was rebuilt
1994	Mae Nawang	Chiengmai	RID	Erosion of spillway due to flood	- lost life - 60 houses were damaged - rice fields were damaged
	Mae Tak Nua	Lumpang	RID	N/A	- 146 houses were damaged - 3 villages were flooded - rice fields were damaged
	Mae sluang	Chiengmai	LDD	Spillway blockage	- 10 houses were damaged - loss of properties by 20 households
	Mae Thang	Phrae	RID	Flood during construction	- overtopping the dam - erosion on d/s slope - damaged section of dam was rebuilt
	Mae Skuen	Phrae	RID	Erosion on spillway foundation	- spillway was redesigned and rebuilt
1997	Huai Sala	Srisaket	RID	Spillway uplift	- damaged section was rebuilt

Existing dams

Nearly 5000 dams have been constructed by a number of government agencies including ; Royal Irrigation Department (RID), Electricity generating Authority of Thailand (EGAT), Office of Accelerated rural Development (ARD), Land Development Department (LDD), Department of Energy Development and Promotion (DEDP), Provincial Waterworks Authority sectors (PWA).

The privates such as land developers, farmers etc. own some small dams in which the capacity less than 500,000 cu.m. Table 3 shows the distribution of Thai dams by the time of construction and owners. And Table 4 shows the distribution of storage capacity. The present need for water demand and flood control in Thailand will lead to the dam construction of 20-30 large and medium scale projects each year.

Table 3 Distribution of Thai Dams by Owner and Decade of Construction

Agency	No. of Dams	Year					Remark
		1947-56	1957-66	1967-76	1977-86	1987-96	
RID	4083	102	51	31	2300	1599	Up to 1994
EGAT	30	-	3	4	14	9	Up to 1995
ARD	329	-	-	64	168	94	Up to 1995
LDD	439	-	-	-	208	231	Up to 1995
DEDP	7	-	-	-	2	5	Up to 1995
PWA	1	-	-	-	-	1	Up to 1995
Total	**4889**	**102**	**54**	**99**	**2692**	**1939**	

Table 4 Distribution of Thai Dams by Owner and Reservoir Storage Capacity

Agency	No. of Dams	Reservoir Capacity (MCM)				Remark
		<1	1-20	>20	Total	
RID	4083	3440	521	49	4010	Up to 1994
EGAT	30	5	7	14	26	Up to 1995
ARD	329	210	73	-	283	Up to 1995
LDD	439	433	6	-	439	Up to 1995
DEDP	7	1	2	4	7	Up to 1995
PWA	1	1	-	-	1	Up to 1995
Total	4889	4090	609	67	4766*	

* Number is less than the exact total number of dams because information on reservoir capacity is not available for some dams

Dam safety status in Thailand

The dam safety program is generally as a technical process to assure that all dams will maintain their structural and operational safety over the service life of the dams. This is accomplished by establishing and enforcing acceptable design, construction, operation and maintenance standards for dams.

Thailand in the past, there is no code of practice that address the responsibility of dam owners for dam safety procedures or emergency action plan in the event of dam failure. EGAT is the first organization who managed the dam safety program in 1982 following nearly fail Ubolratana Dam. The Civil Maintenance Department was established to responds to dam safety activities and issued a regulation for inspection and safety evaluation of EGAT's dam. After the failure of the Upper Mun Dam, RID appointed a Dam Safety Committee to inspect RID large dams. And Dam Safety Inspection and Evaluation Center was established in 1990 to serve as the secretariat to the Committee and coordinate RID's dam safety effort. While other dam owners do not have formal dam safety dam safety program yet.

3. USING OF CONDITION INDEX SYSTEM

Concept of Condition Index

Several methods of dam safety evaluation had been proposed such as Hazard Potential Classification, Priority Rating Criteria, Condition Index System (USACE, 1995) and Risk Analysis etc. The U.S. Army Corps of Engineers used condition index systems for roads, navigation locks, miter lock gates, steel-sheet-pile structures etc. since 1976. The important aspects of this system are not only for safety evaluation of the structures in the quantified scale but also providing the priority order for maintenance and repair. The structure will be separated into components and subcomponents as many levels as we want, and the influences among them are also considered. So that of some important component was damaged, it will affect or cause the progressive damages to many other related components. Those components who have more influences to others will be assigned more weight factor in the score calculation. The dams are extremely complex civil engineering facilities. They are consisted of several components or subcomponents and interaction between them, thus condition index system is the excellent basic tool for dam safety evaluation.

The simple model for dam condition index system without component interaction is given on Figure 1. And more complex model staring with damage behaviors (objectives), relating components and interaction matrix is shown Figure 2.

Finally, the condition index scale (CI-Dam) is reflected an assessment of the current physical state of components of a dam. This number indicates a given level of deterioration or loss of its function as comparing to ideal condition. The judgement scale developed by the USACE is composed of seven general levels in term of state of deterioration or loss of functionality. The reccommended actions corresponding to each CI-levels are also given as described on Table 5

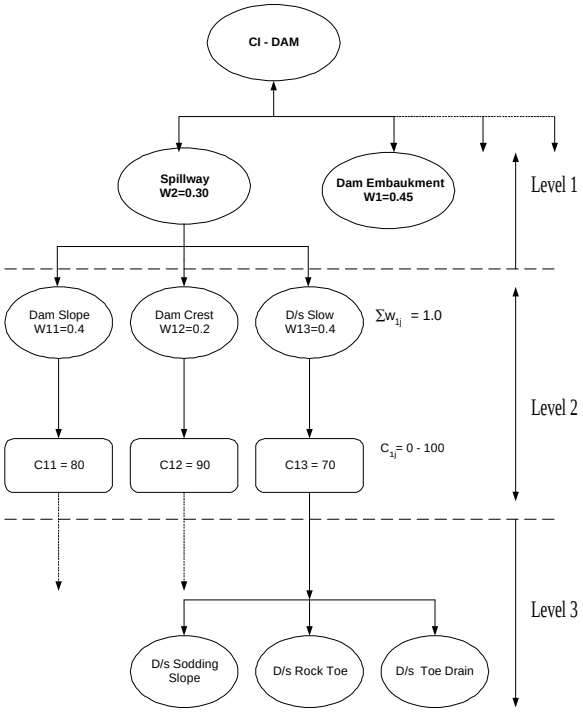


Figure 1 Simple Model of Dam Condition Index System

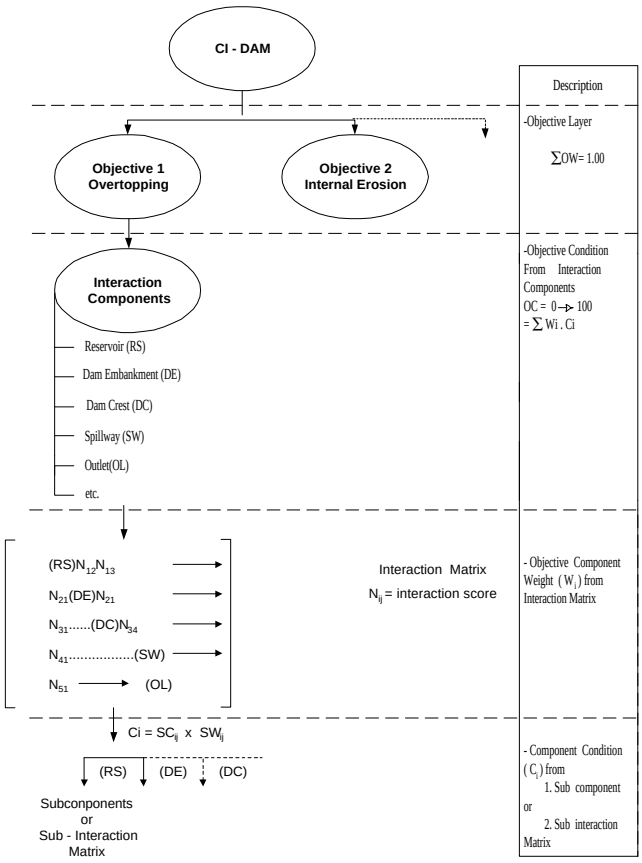


Figure 2 Complex Model of Dam Condition Index System

Table 5. Condition index scale and zones.

Zone	Condition Index	Condition Description	Recommended Action
1	85 to 100	Excellent: No noticeable defects. Some aging or wear may be visible	Immediate action is not required
	70 to 84	Good: only minor deterioration or defects are evident.	
2	55 to 69	Fair: Some deterioration or defects are evident, but function is not significantly affected.	Economic analysis of repair Alternatives is recommended to Determine appropriate action.
	40 to 54	Marginal: Moderate deterioration. Function is still adequate.	
3	25 to 39	Poor: Serious deterioration in at least some portions of the structure. Function is inadequate.	Detailed evaluation is required to determine the need for repair, rehabilitation or reconstruction. Safety evaluation recommended.
	10 to 24	Very Poor: Extensive deterioration. Barely functional.	
	0 to 9	Failed: No longer functions. General failure of complete failure of a major structural component.	

Model for RID's Dams

The application of condition index system for dam evaluation in Thailand combines the advantages both simple and complex model to suit for the local practices. First, the overall dam condition (CI-dam) was devided into two abstract components, The status information and condition of dam are evaluated by Field Inspection as shown on Figure 3.

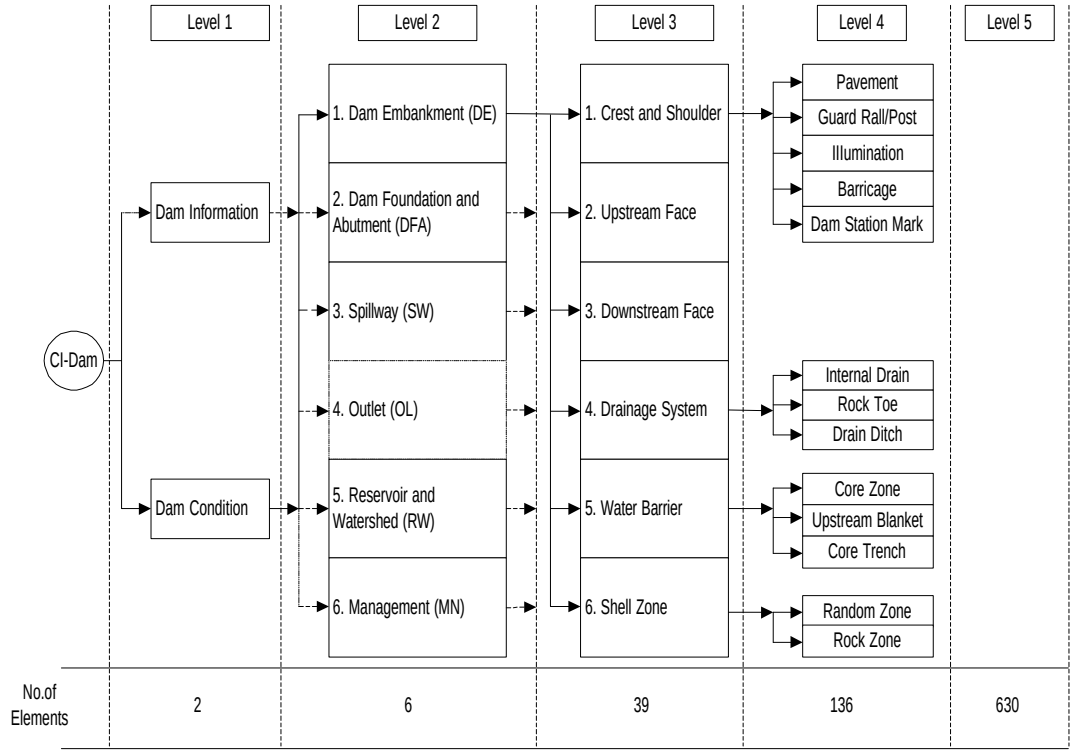


Figure 3. Condition Index model for RID.9's dams**.**

The status of dam information indicates the degree of completion of the relevent documents such as history of dam, investigation and design reports, drawings, completion report after construction, operation and maintenance data etc. that should be appropriately presented at site, provincial or regional offices. While the conditions are the present state of existing dam comparing to ideal dam condition inspected in the field. The relative weight factors between the information and condition given on Table 6.

Table 6. Relative Weight Factors for Level 1.

Dam size	**Dam height (h), meter and Reservoir storage (v), MCM**	**Weight Factor (w)**			
		First 5 years		**After 5 years**	
		Information	**Condition**	**Information**	**Condition**
Small	5 ≤ h and 0.05, ≤ v < 1.0	10	90	20	80
Medium	1.5 ≤ h < 30 and 0.5 ≤ v, 100 or 10 ≤ h < and 1.0 ≤ v < 100	15	85	25	75
Large	h > 30 and V > 10 Or h > 20 and v > 100	20	80	30	70

4. EVALUATION PROCESS

The dam safety evaluation was first applied for 32 dams in the eastern Part of Thailand (RID. Regional Office No. 9). The evaluation procedures are as shown on Figure 4. Staring with the compilation of information during investigation-design and construction stages which was collected into the dam data base. Then the dams were carefully inspected by the technical team, and field data were collected in the data base. After the condition index scores were calculated then the implementation of

result such as routine maintenance, repair, rehabilitation or emergency preparedness are recommended. The Royal Irrigation Department is now using the evaluation data for maintenance budget preparation for the next fisical years.

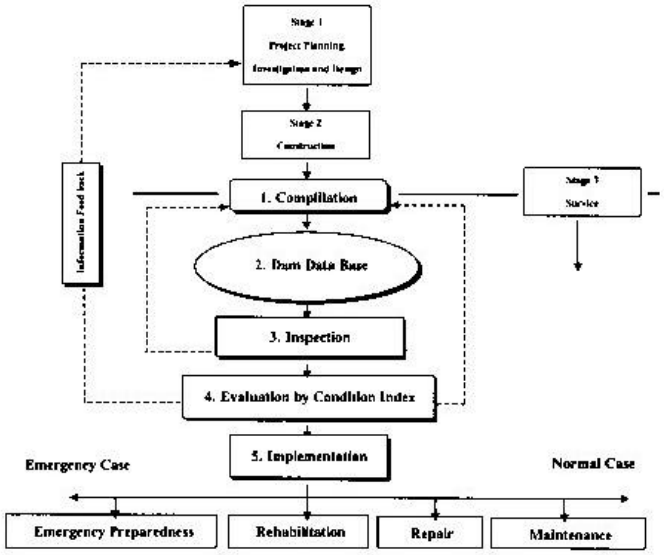


Figure 4 Dam Safety Evaluation Procedures

5. RESULTS

The results from 32 dams evaluation as shown on Figure 5. indicated that the overall condition indexes are mostly in 70 to 84 level. The average, maximum and minimun CI. are 78.27, 83.83 and 69.33 respectively. According to Table 5, the dams generally are in good condition with only minor deterioration thus immediate action is not required. However the dam information indexes show rather poor to fair from 35 to 65. This indication reflects the lack of necessary dam information that should be available in the field and provincial offices.

The overall Condition Indexes show the tendency to increase with the dam height and reservior volume as shown on Figure 6 a) and b). The larger dam generally has the higher standard for investigation, design, construction and maintenance than the small ones.

During the service period the deterioration of several dam components is started and increased with time as shown on Figure 6 c). Hopefully with proper maintenance program the rate of dam deterioration will be slowed down to the acceptable level.

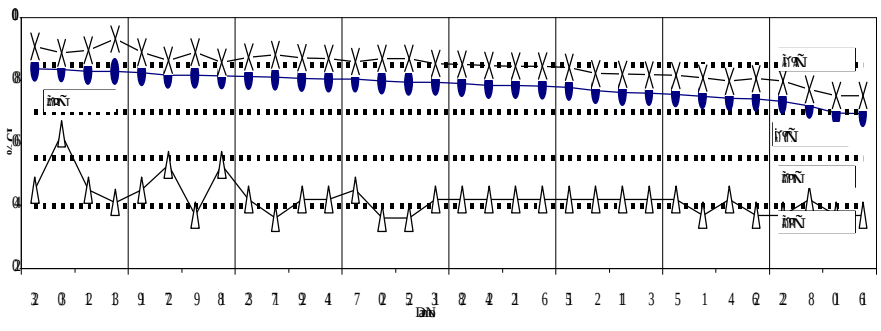
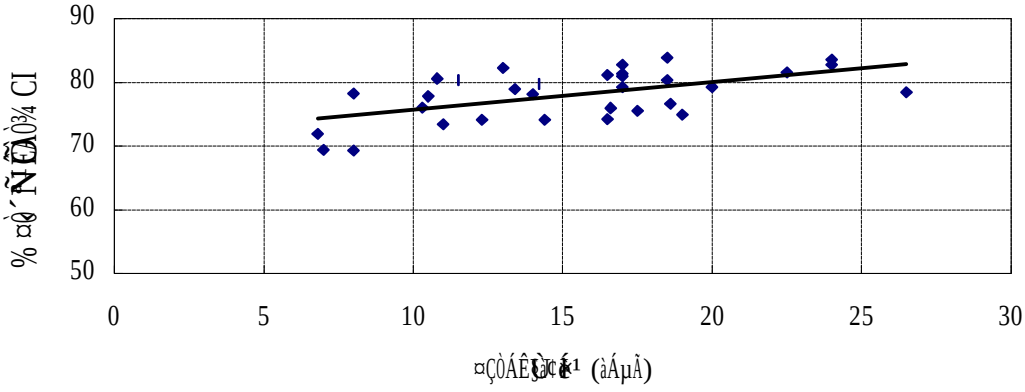


Figure 5 Ranges of Condition Indexes

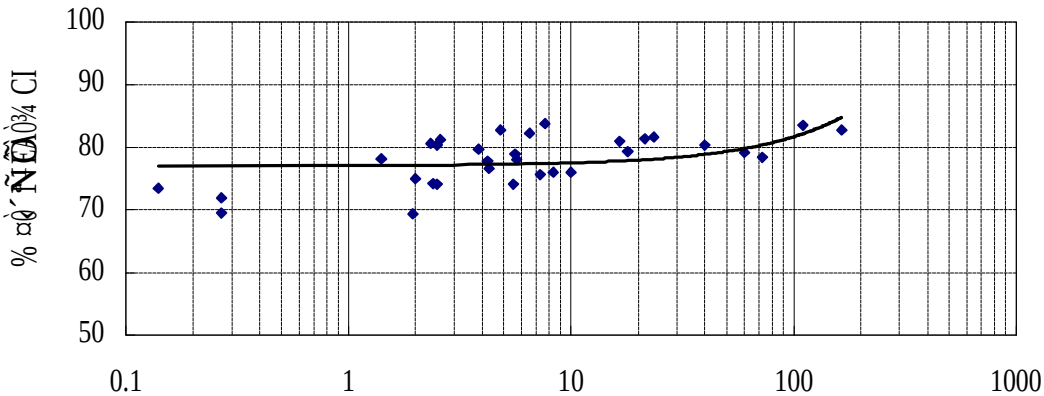
This evaluation system can trace across the condition in any level from the overall dam condition to the smallest inspected components. Figure 7 shows the variation of CI. in level 2 of six major dam components. In average, the dam foundation and abutment is the best while the management for dam maintenance show the lowest score.

If estimated maintenance costs on every inspected items in added to the dam database. Then the dam owner can select the scheme to maintenance the dams by;

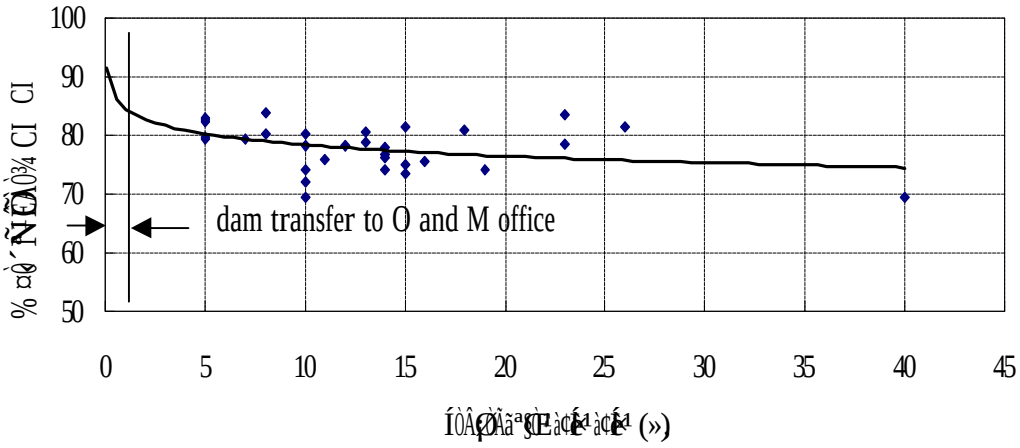
a) lowest CI components to the acceptable standard,
b) lowest available budget and
c) highest ratio of CI/cast (CIC) for must efficient and long-term maintenance.



a) Overall CI. v.s. Dam Height



b) Overall CI. v.s. Reservoir Volume



c) Overall CI. v.s. Dam Age

Figure 6 Relationships of CI. with dam size and age

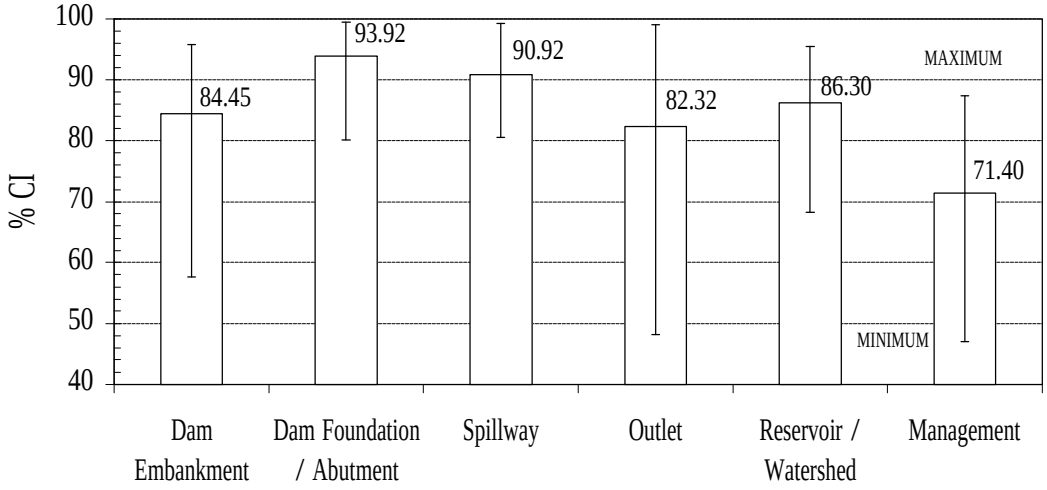


Figure 7 Variation of CI on Level 2 Components.

The example of safety evaluation of Klong Rabom Dam, Chachoengsao Province before and after spillway rehabilitation is given on Figure 8 and 9. The dam is earthfill dam of 18.50 meters high, reservoir capacity of 32.2 MCM. It shows the sign of spillway uplift movement on the last 2 years. After the field inspection and damage assessment done then the rock anchors combined with proper under drain were recommended. The rehabilitation was urgently carried out on time and finished just before the flood that overtopped the spillway. Although the overall CI-scores do not change much but the CI-scores of spillway is clearly reflected the improvement.

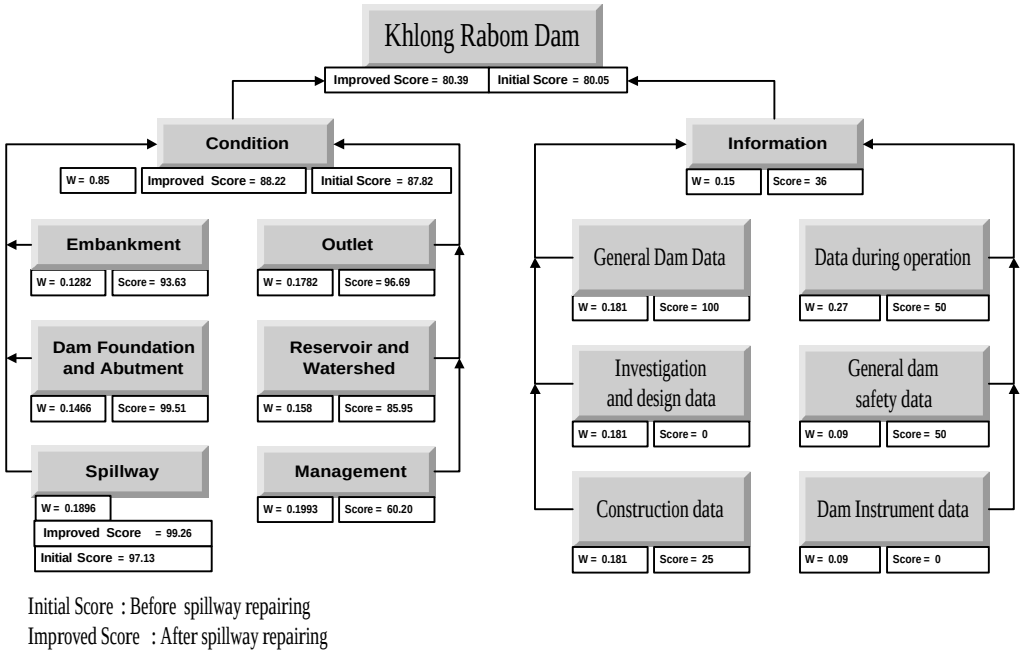
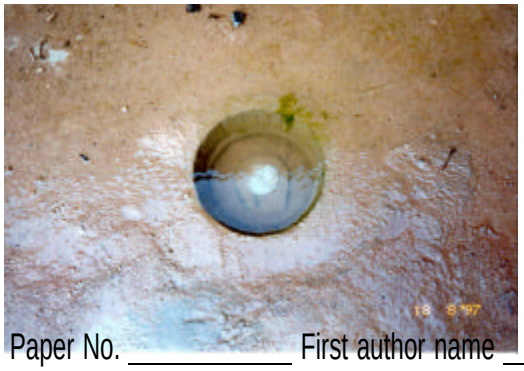


Figure 8 Dam Safety Evaluation of Klong Rabom Dam

a) Existing spillway

b) Piping on spillway flood



c) Providing underdrains and weep holes d) Improved spillway

Figure 9 Spillway Rehabilitation of Klong Rabom Dam

6. FUTURE PROGRAM

The dam safety evaluation program using condition index system is now completed with satisfactory results for 32 dams of RID-Regional Office No. 9. In the future Royal Irrigation Department is going to extend evaluation for other regional office such as RID-Regional Office No. 10. The benefit from this program anable RID. to make a long term maintenance plan and obtain the valuable information for future design and construction. Geographical Information System for dam and reservoir operation are now carrying simultaneously for effective irrigation water management. Some potential hazard dam will be selected for dam break analysis and installation of dam instrument warning system.

7. CONCLUSION

1. The numbers of storage dams in Thailand are close to 5,000 dams at the present, Although there are no catastrophic dam failure incident happened up to now but many dams are quite old relative to the design life.
2. Electric Generating Authority of Thailand (EGAT) and Royal Irrigation Department (RID) are the government agencies who own about 80 percent of the dams in Thailand. Both organizations are already setup the dam safety program to evaluate their own dams.
3. The Condition Index System was successfully used for dam safety evaluation for 32 dams in RID-Regional Office No. 9 and has a possibility to extend to other area in the future.
4. This evaluation system give the condition index scale (CI) that converts an assessment of the current physical state of dam components and also status of dam information available
5. The evaluation of 32 dams in eastern Thailand shows the overall condition indexes between 70 to 84. The low scores for dam information indexes reflect the lack of necessary documents in the field and provincial office.
6. The overall condition indexes show the relations with dam height, reservoir volume and service period.
7. The condition index system can combine to maintenance cost database for effectively management of maintenance program and budgeting.
8. Implementations of the results from dam safety evaluation can be ranged from systematic maintenance to public warning or emergency preparedness.
9. Dam data base obtained from the evaluation procedure can also be valuable informations for future uses for the water resource planners, dam designers, O and M officers and budget officers.

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