# Engineering Geological Asset Management for Large Dams

Yasuhito SASAKI[1]

(1) Geology Research Team, Public Works Research Institute, Japan
E-mail:ya-sasa@pwri.go.jp

**Abstract**

Comprehensive inspection for asset management has recently started for almost all infrastructures controlled by the Japanese Ministry of Land, Infrastructure, Transport and Tourism (MLIT). The inspection has also proceeded for old large dams constructed before 30 years ago, which occupy about 45% of all large dams of MLIT. The temporal inspection results revealed that 4 types of engineering geological problems have often occurred, namely deformation of dam or its foundation (temporal occurrence rate; 27%), water problems such as leakage, erosion and rise in uplift pressure (13%), deterioration in rock materials (20%), and slope movements or landslides near dams or reservoirs (37%). Though the above occurrence rate is temporal one by the author's experience, it suggests that the foundations of dams and reservoirs also deteriorate. As these deteriorations proceed by geological mechanisms, we have to detect the deterioration, clarify the mechanism, analyze the deterioration speed and its influence to dam, and plan countermeasures by engineering geologically effective methods. The above PDCA cycle is engineering geological asset management (EGAM) and is challenging field for future engineering geology. In this paper, the concept of EGAM is discussed with some inspection cases.

**Keywords**: large dam, asset management, deterioration, foundation, engineering geology

## 1. Introduction

Asset management for the maintenance, longevity and safety of old infrastructures becomes important issue in the world. Especially, dam should be one of the most long-lived and safe infrastructure. Then, comprehensive inspection for asset management has recently started for large dams controlled by the Japanese Ministry of Land, Infrastructure, Transport and Tourism (MLIT). The inspection has proceeded for old large dams constructed before 30 years ago.

Generally, dam is thought to be durable and engineering geological problems on foundations may be few. But, after the above inspection, some engineering geological problems were found in many dams. In this paper, such cases are introduced and desirable procedure is proposed for engineering geological asset management of large dams.

## 2. Outline of large dams for flood control and the asset management system in Japan

### 2.1 Number of large dams

Number of large dams (over 15m in height) for flood control are 551 dams in 2014 (Fig.1). 121 dams are directly controlled by MLIT and Japan Water Agency (JWA) and Okinawa General Bureau (OGB). 430 dams are controlled by prefectures under the support of MLIT. 45% of these dams are over 30 years after completion, 25% are over 40years and 11% are over 50 years.

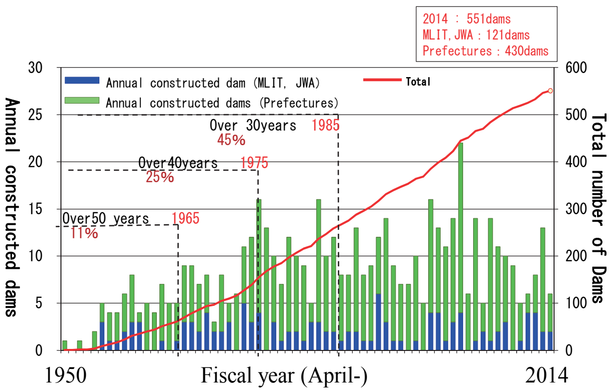


Fig.1 Number of large dams for flood control in Japan

### 2.2 Asset management system of large dams in Japan

MLIT prepared out a set of program for asset management for large dams as below.

a. *Technical Criteria for River Works (volume of Dam Maintenance), 2014. (TSDM)*

b. *Manual for Comprehensive Inspection of Dam, 2013. (MCI)*

c. *Manual for Periodical check for Dam, 2015 (draft) (MPI)*

*Technical Criteria for River Works* is the most comprehensive standard for river works in Japan, which contains not only river works but also slope disaster prevention works and dam works etc. *Volume of dam maintenance (TSDM)* is recently established, it regulates general dam maintenance procedure. *MCI* regulates comprehensive inspection of old dam after constructed 30 years, the inspection will be performed every 30 years. *MPI* regulates periodical inspection, which will be performed every 3 years.

In addition, daily check, and urgent check after earthquakes or floods are performed.

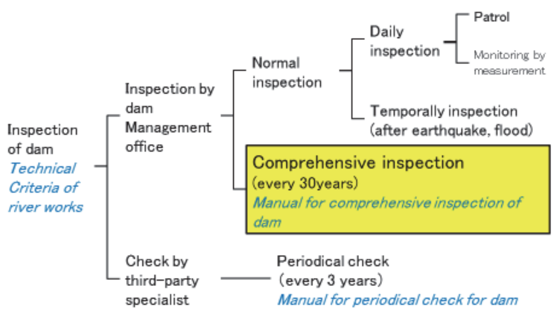


Fig.2 Inspection system of large dams for flood control in Japan.

### 2.3 Comprehensive inspection by MCI system

Comprehensive inspection of old dams based on *MCI* system has formally started in 2014 after trial run. The inspections on 7 dams have finished by MLIT, JWA and OGB in 2014 fiscal year, and the inspections on 30 dams are now in practice.

MCI system is outlined as follows and Fig.3.

At first, every part facilities and structures of a dam are classified three maintenance levels (importance levels). For example, dam body, foundation of dam, slopes near dam and landslide countermeasure facilities are high level, and the light of roadway of dam crest is low.

Treatment of maintenance is selected as Table 1, namely final treatment is selected with the combination of maintenance level and lank of soundness.

## 3. Engineering geological problems of old dams

The author has participated in the MCI system making and inspections as engineering geologist since trial run period. In this experience, 4 types of engineering geological problems have often observed in old large dams, namely,

1) Small displacement of joint or cracks of dam body or related facilities caused by the deformation of dam bodies, facilities, or by these foundations (occurrence rate; 27%)
2) Water problems such as leakage, erosion and rise in uplift pressure (13%)
3) Deterioration in rock materials (20%)
4) Slope movements or landslides near dams or reservoirs (37%).

The above occurrence rates are based on temporal data in my experience, more accurate data may be published by MLIT in future.

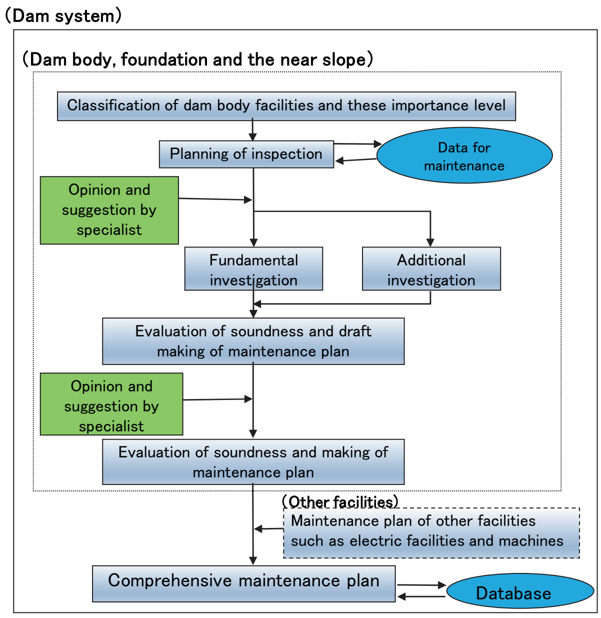


Fig.3 Flow of MCI system. (MLIT, 2013)

Table 1 Relationship between maintenance level, lank of soundness and treatment of maintenance, (MLIT, 2013)

| | | | Maintenance level of facilities (importance) | | |
|---|---|---|---|---|---|
| | | | High | Medium | Low |
| Lank of soundness | a1 | ○Need urgent measures | Preventive maintenance, urgent measure | Preventive maintenance, urgent measure | After the fact maintenance, measure |
| | a2 | ○Need prompt measures | Preventive maintenance, urgent measure | Preventive maintenance, measure | After the fact maintenance, priority monitoring, or measure |
| | b1 | ○Need measures in near future | Preventive maintenance, measure | Preventive maintenance, priority monitoring, or measure | After the fact maintenance, or no maintenance |
| | b2 | ○Need measures in future | Preventive maintenance, priority monitoring, or measure | Preventive maintenance, monitoring | After the fact maintenance, or no maintenance |
| | c | ○No need measures ○Sound | Preventive maintenance, monitoring | Preventive maintenance, monitoring | After the fact maintenance, or no maintenance |

## 4. Case study

### 4.1 Deformation of dams or related facilities

Photo.1 is an open crack along a transverse joint of a gravity dam. This crack is thought to have opened by a strong earthquake. This transverse joint exists just on steep and partly over-hanged foundation. Therefore, loosen rock mass, which has been formed by river erosion in long period, may affect the occurrence of open crack. But it is generally difficult to determine the cause. Therefore, in this case, drilling surveys and borehole observations were performed to confirm the stability of foundation.

Photo.2 shows small displacement of a joint of training wall of stilling basin. In this case, it was uncertain when and why the displacement has occurred. Furthermore, there was no information of the foundation. Then, some drilling investigation and the monitoring of deformation by inclinometer and groundwater table are performed.

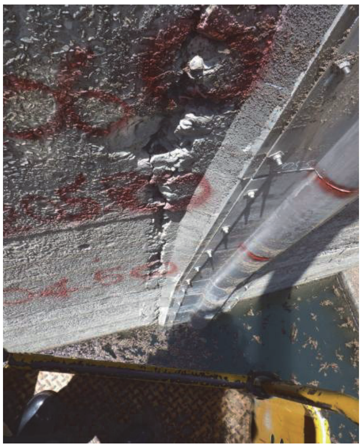

Photo.1 Open crack along a transvers joint

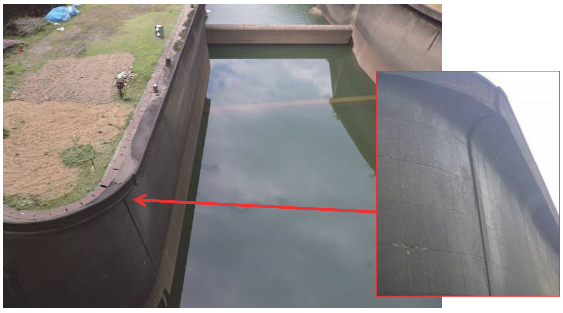

Photo.2 Displacement of a joint of training wall of stilling basin

### 4.2 Problems on ground water and surface water

Photo.3 is leakage water from a retaining wall which is located in the downstream of a dam. The water passed under the dam foundation or right hand rim grout line. The geology is the Tertiary volcanic rocks, and there are many cooling joints in the rock mass. It is generally difficult to find the leakage route. Therefore, in this case, contour maps of ground water table and its change in time series were checked along the dam site and downstream to clarify abnormal ground water table zone.

Photo.3 Leakage water from dam

Photo.4 is the collapse of a weir (not large dam). The weir was constructed about 80 years ago and the foundation was partially river deposit, and the deposit was eroded by flood stream or groundwater pressure.

Photo.4 Collapse of a weir by erosion of foundation

### 4.3 Low quality of rock and soil materials

Photo.5 is the deterioration of rip lap of a rock fill dam. In this case, the cause is thought to be low quality of rock material against freezing and thawing because some rocks are porous and contain clay minerals. But many rocks are sound, dam is totally evaluated as sound.

Photo.5 Deterioration of rip lap of rock fill dam by freezing and thawing

Photo.6 is a rock fill dam after repaired rip lap rock material. The rock contains laumontite and deteriorated by the repetition of dry and wet. This dam was covered with soil to prevent the repetition of dry and wet for downstream side, and replaced with rocks of good quality for upper stream side.

Laumontite is also problematic for dam concrete. Photo.7 and photo.8 is the case. The aggregate is mainly sandstone and contains laumontite in matrix. In this case, deteriorated surface of dam concrete was scraped and covered by 30cm thick of new concrete of good quality.

Photo.6 A rock fill dam after repaired laumontite bearing rip lap rock. (Left photo is trench investigation for checking deterioration.)

Photo.7 Crack and pop up of dam concrete. (The aggregate contains laumontite.)

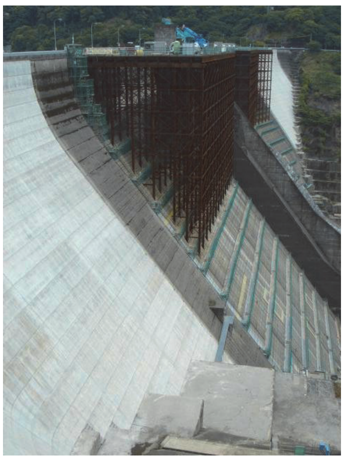

Photo.8 Repairing of dam concrete. (Same dam as photo.7)

**4.4 Slope movements, landslides**

Photo.9 is a rock shed on a dam crest. Huge rock masses distribute on slopes near the dam. Not only dam managers but also visitors in sightseeing are dangerous, then the dam office has constructed some countermeasures such as shed, rock net, and rock anchor around the dam.

Photo.9 Rock shed on a dam crest

Photo.10 is a landslide block near the outlet of arch dam. The management office of the dam in the photo was constructed on the landslide, because this district is very mountainous and there was no flat or gentle slope near the dam except for the landslide. In this case, monitoring of the landslide movement is performed long time, the movement is very small.

Photo.10 Landslide near a dam

Photo.11 is a landslide near a reservoir. The landslide topography is matured, therefore the landslide is thought to have moved for long time before the dam construction. The abutment foundation of the road bridge is on the landslide, and deformed several cm/year by landslide movement.

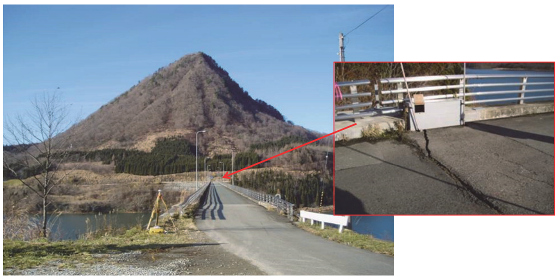

Photo.11 Landslide near reservoir and a bridge on it.

### 4.5 Lack of geological data

Photo.12 is a very old dam. The construction has started from 1941, stopped by World War Ⅱ, and completed in 1954. Therefore, geological data, maps and documents are few, even foundation sketch data does not exist. The lack of geological data has become a big problem for administration because weak serpentine widely distributes in this area and it was impossible to estimate the stability of the dam. Then drilling survey was conducted. Finally, the survey revealed that the foundation was not serpentine but tight and strong amphibolite rock.

Photo.12 Old dam constructed before and after World War Ⅱ.

## 5. Discussions

### 5.1 Engineering geological problems and necessary technique

Table 2 shows the above engineering geological problems in old dams, necessary techniques for asset management and maintenance of them. Table 2 dares to include ideal problems such as the displacement of dams by active fault. There is no problem on the displacement of dams by active faults in Japanese flood control dams.

The necessary techniques contain already using techniques and developing techniques. It is important for engineering geology to develop the techniques.

### 5.2 Importance of engineering geological aspect in asset management

The above many cases suggest that the foundations of dams and reservoirs also deteriorate, deform and move in long time. Foundation asset management (FAM) is very important. Unfortunately, the concept of FAM is insufficient even in the MCI system. As these deteriorations of foundations proceed by geological mechanisms, engineering geologists should improve the scheme of MCI.

Vessely (2011) published a technical report sponsored by Federal Highway Administration (FHWA) in the USA on the concept of Geotechnical Asset Management (GAM) for the maintenance of geotechnical structures of roads such as retaining wall, embankment and slope disaster prevention facilities. However, for the above purpose, not only geotechnical aspect but also geological aspect are need for the estimation of life cycle cost or longevity, because the deterioration of geotechnical structures proceeds with weathering and erosion of foundation. Forecasting of these phenomena should be a task of

Table 2 Engineering geological problems in old dams and future necessary technique

| Engineering geological problems in old dams | Necessary technique |
|---|---|
| (Deformation of dam and foundation)<br>・Displacement, open crack, subsidence deformation of dam and related facilities caused by foundations (dam body and joint, spillway, training wall, footing, etc.) | ・Investigation method to determine the cause of deformation or displacement<br>・Evaluation method for stability of foundation<br>・Monitoring and forecasting of deformation in long period<br>・Repairing method |
| (Problems on ground water and surface water)<br>・Leakage water (Increase of leakage, Occurrence of muddy water from drain hole under dam)<br>・Increase in uplift pressure<br>・Erosion and piping of foundation | ・Investigation of groundwater flow<br>・Investigation to determine the cause of uplift<br>・Evaluation of erosion resistance<br>・Monitoring and forecasting of deterioration in long period<br>・Repairing method |
| (Low quality of rock and soil materials)<br>・Deterioration of rock materials (concrete aggregate, rip lap rock of fill dam, etc.)<br>・Deterioration of dam materials or earth structures (by freezing and thawing, alkali aggregate reaction, etc.) | ・Investigation method to determine the cause of deterioration<br>・Monitoring and forecasting of deterioration in long period<br>・Repairing method |
| (Slope movement, landslides)<br>・Landslides, rapid slope failures (dam slopes, cut slopes, banks, reservoir slopes) | ・Stability evaluation of reservoir landslide<br>・Forecasting destabilization by wave erosion<br>・Efficient monitoring<br>・Assessment of influence of rapid landslide<br>・Countermeasure of rapid landslide |
| (Active fault)<br>(There is no problem on the displacement of dam in Japan because all large dams have been avoided constructing on active faults.) | ・Distinguish method of active or non-active<br>・Evaluation method of activity in mountain area<br>・Assessment of influence of active fault |
| (Lack or insufficiency of information)<br>・Luck of geological data of foundation or monitoring data | ・Investigation of the foundation of old dams and reservoirs, and making these database |

engineering geologists.

### 5.3 Procedure of engineering geological asset management

Engineering geologists have to *detect* the deterioration of foundations and its change, *clarify* the mechanism, *analyze and forecast* the deterioration speed and its influence to structures, and *plan* countermeasures by engineering geologically effective methods. The above PDCA cycle is just Engineering Geological Asset Management (EGAM) and is challenging issue for future engineering geology.

For example, in the case that the deterioration of a cut slope by weathering was found near a dam, we have to investigate not only weathering depth and the strength of deteriorated rock mass at present but also estimate deterioration speed, slope stability in future, influence for dam and the long-term effectiveness of various countermeasures. After that, we have to propose the best countermeasure and its execution time in the viewpoint of cost and safety. Especially, it is important to estimate deterioration speed and the change of stability in future, this will be a core mission for engineering geologists.

Engineering geological investigation in the construction stage is mainly performed by direct methods such as drilling surveys or edit tunnels to know *geology and engineering geological values*.

But in the maintenance stage, we have to know *these changes for long period*. It is a difficult task and needs very precise investigations. Furthermore, the direct methods are restricted because old structures exist on the foundations and the structures are still used.

Therefore, multiple investigation should become more important, which consists of direct methods, non-destructive methods such as geophysical survey, field measurements and monitoring.

Conceptual flow of EGAM is shown in Fig.4. The examples of technique contain not only commercial techniques but also developing and conceptual techniques. Engineering geologists should improve these techniques and EGAM system to contribute to make sustainable world.

## 5. Conclusions

Comprehensive inspection of old large dams has started and revealed that 4 types of engineering geological problems have often occurred, namely deformation of dam or foundation (temporal occurrence rate; 27%), water problems such as leakage, erosion and rise in uplift pressure (13%), deterioration in rock materials (20%), and slope movements or landslides near dams or reservoirs (37%). To detect such problems and propose effective measures, the concept of Engineering Geological Asset Management (EGAM) are proposed. To progress EGAM, it is important to improve the precision of engineering geological investigation and monitoring, simulation and evaluation techniques on long deterioration of foundations.

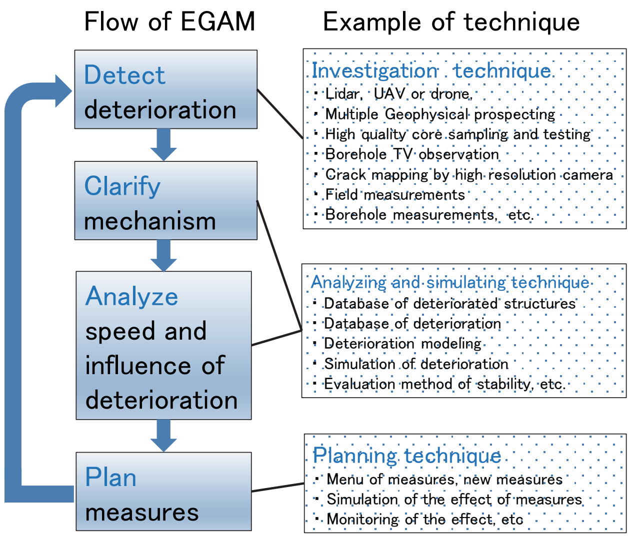


Fig.4 Conceptual flow of EGAM

## Acknowledgements

The author is grateful to the members of dam offices in MLIT and Prefectures reported above.

## References

The Japanese Ministry of Land, Infrastructure, Transport and Tourism (2013): Manual for comprehensive inspection for dam, 112p.

The Japanese Ministry of Land, Infrastructure, Transport and Tourism (2014): Technical criteria for river works; practical guide for the maintenance of dam, 67p.

Vessely,M (2013): Geotechnical asset management –implementation concept and strategies-, No.FHWA-CFL/TD-13-003,62p.