ENGINEERING FOR RAISING DAMS IN JAPAN

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1. Introduction

It has been becoming difficult to construct new dams in Japan due to financial pressure on public works and growing social concerns on the preservation of nature. In addition, suitable sites for dam construction are becoming scarce. For these reasons, it is important to effectively utilize existing dams for flood mitigation and water supply in the future. On the other hand, technical problems related to the modifications for improving existing dams and establishment of discharge facilities are becoming important.

Subcommittee for the Research on Effective Use of Existing Dams of Japan Commission on Large Dams (JCOLD) published the report on the examples and trend of effective use of existing dams on 2004[1)]. JCOLD subcommittee for the Research on Dam Refreshment was established on 2005 for the purpose of examining technical problems related to the effective use of existing dams mentioned in the previous subcommittee report. Through the research works of the subcommittee for two years, the cases related to designs and construction works for the effective use of existing dams were collected and analyzed[2)]. The research works are categorized as follows: a) the raising methods of existing dams, b) improvement works methods of outlet works, and c) reservoir maintenance methods for sedimentation. As a result, problems related to the dam refreshment were pointed out and the methods solving those problems were examined. This paper introduces the "Engineering for raising construction of existing dams."

2. Raising of Existing Dams

Engineering for raising construction of existing dams are necessary for utilizing existing dams and increasing the reservoir capacities in a dam improvement scheme. A difference between the raising work of an existing dam and the construction work of a new dam is the existence of constraints on the reservoir management during the dam's modification period, i.e., whether to keep flood control and water utilization functions or to regulate a part of these functions. If the constraints on flood control and water utilization during the reconstruction period will last for a long period of time, it may be a hindrance to downstream stakeholders and residents. Thus, a flexible reservoir management will be necessary for minimizing such constraints on reservoir management and shortening the reconstruction period, and, therefore, technologies necessary for these conditions will become important.

3. Concrete Dams

(1) Research objective Dams

Examples of the existing concrete dams whose heights were raised are listed in Table 1. As shown in Figure 1, the method for raising their heights is follows: a) their heights were raised towards the downstream side maintaining the same dam axis, b) their heights were raised near the energy dissipater, and c) their heights were raised on the upstream side maintaining the same dam axis. For cases a) and b), construction works can be conducted without emptying the reservoirs. For case b), the dam volume will become larger than that of case a). For case c),

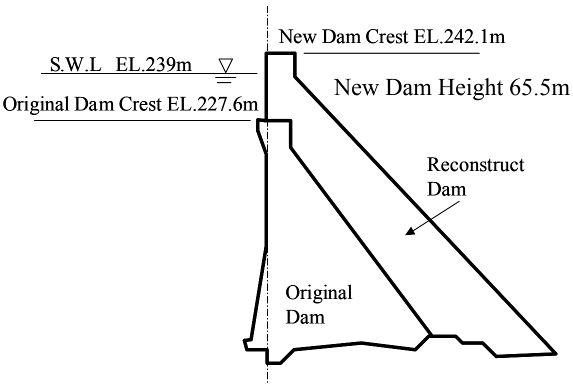
Table 1 List of Researched Raising Concrete Dams

Name of Dam	Projecte Agency	Dam Purpose	Dam Type	Year Completed	Raising Work	Dam Height (m)		Raised Location
						Original	Modified	
Mikawa	Agricultural Bureau	A→AWI	G	1960	1969～1972	48.0	53.0	a) downstream
Kawakami	Yamaguchi Prefect.	FI→FWI	G	1962	1976～1979	46.5	63.0	a) downstream
Kuroda	Chubu Elect. Power	P	G	1934	1973～1980	29.5	46.0	a) downstream
Shinnakano	Hokkaido	W→FNW	G	1960	1971～1984	53.0	74.9	a) downstream
Ohaku	Chugoku Electric	P	G	1959	1987～1989	63.5	74.0	a) downstream
Magaribuchi	Fukuoka Prefect.	W	G	1923	1989～1993	37.0	45.0	c) upstream
Sakamoto	Gunma Prefect.	Debris→N	G	1958	1985～1994	34.0	36.3	c) upstream
Kayaze	Nagasaki Prefect	FW→FNW	G	1961	1981～2000	51.0	65.5	a) downstream
Mitaka	Hiroshima Prefect	W→AW	G	1944	1999～2004	32.6	44.0	a) downstream
Taishakukawa	Chugoku Electric	P	G	1931	2002～2006	62.1	62.4	a) downstream
Simonohara	Sasebo City	W	G	1968	1995～2006	30.6	36.5	a) downstream
Yasugawa	Agricultural Bureau	A	G	1951	1998～2009(under construction)	52.7	54.4	a) downstream
Hikawa	Kumamoto Prefect.	FNAW	G	1973	1990～2010(scheduled)	56.5	58.5	a) downstream
Nagara	Kagawa Prefect.	FN	G	1953	1995～2011(scheduled)	30.0	42.0	a) downstream
Shinkaturagawa	Hokkaido Dev. Agen.	FAWP →FAWIP	G	1957	1985～2014(scheduled)	63.6	75.5	a) downstream
Shinmaruyama	Chubu Const. Bureau	FP→FNP	G	1955	1980～2016(scheduled)	98.2	122.5	b) downstream (E. dissipater)
Shinpogawa	Niigata Prefect.	F→FN	G	1972	1991～2017(scheduled)	29.0	38.0	a) downstream

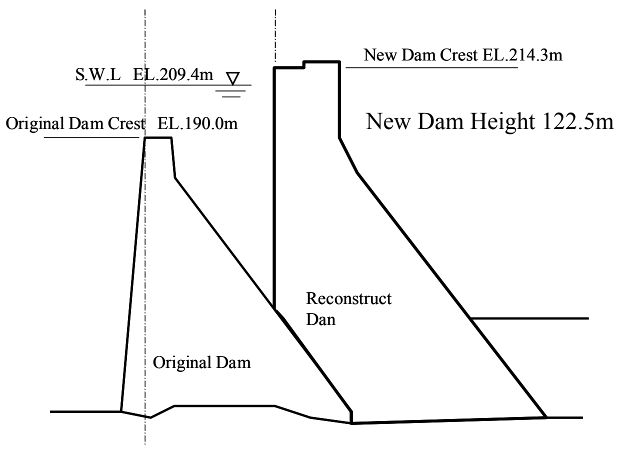
Purpose: F: Flood Control N: Multipurpose Use A: Irrigation W: Drinking Water I: Industrial Water P: Hydropower
Dam Type G: Gravity Concrete R: Rockfill E: Earth A: Arch

constraints on the downstream land will be small, but the reservoir has to be emptied and concrete is to be placed on the upstream side of the original dam body. As an example of case a), Photo 1 shows the raising work of Kayaze Dam.

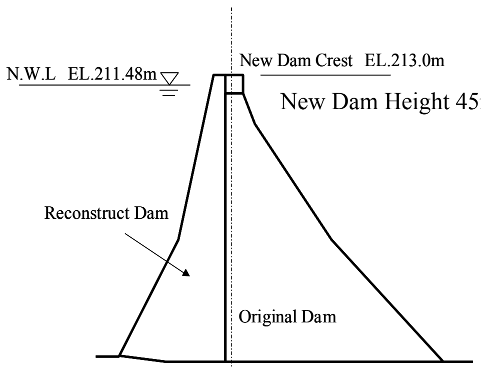
Photo 1 Raising Work of Existing Dam (Kayaze Dam)[3)]



a) Raised on downstream side with same dam axis (Kayaze Dam)



b) Raised on downstream side (Shin Maruyama Dam)



c) Raised on upstream side with almost the same axis of the original (Magaribuchi Dam)

Fig. 1 Example of Raising Concrete Dams

Table 2 Diversion Method and Design Discharge for Raising Concrete Dams

Case	Name of Dam	Diversion Method	Design Discharge
Combined Use of New and Original Facilities	Shin Maruyama	a) Power Generation & Diversion Tunnel b) Temporary Diversion Tunnel c) Existing Dam Gates	a,b,c) Equal to design high water discharge for original dam during a flood season. a,b) 1/1-year probability during non-flood season.
	Kuroda	a) Existing Discharge Pipe b) Diversion Channel in Dam Body	a,b) Q=22m^3/s, 1/1-year probability
	Kayaze	a) Temporary Diversion Tunnel b) Existing Conduit Gate	a) 1/50-year probability b) Equal to design high water discharge of original dam
	Nagae	a) Existing Crest Gates for Flood Control b) New Intake for Normal Flow	a) Design high water discharge b) 1/2-year probability during non-flood season
	Mitaka	a) Temporary Diversion Channel (Open Channel) b) Temporary Diversion Channel in Dam Body	a) Max discharge in 10 years in non-irrigation season. b) 2/1-year probability
	Sakamoto	a) Existing Intake Facility b) Temporary Diversion Channel	a) Q=24m^3/s, 2/1-year probability b) Q=70m^3/s, 1/2-year probability
New Facility	Shin Nakano	Temporary Diversion Tunnel	Q=40m^3/s, 1/2-year probability
	Shin Katsurazawa	Temporary Diversion Tunnel	Design max discharge for original dam.
	Magaribuchi	Temporary Diversion Tunnel	1/2-year probability
	Shimonohara	Temporary Diversion Channel (part of dam body was cut off.)	1/1-year probability
Use of Existing Facility	Shinpogawa	Existing Spillway	Designed flood discharge for original dam
	Hikawa	Existing Spillway (Main Gate)	Designed high water discharge Q=150m^3/s
	Yasugawa	Existing Outlet	Designed high water discharge Q=10.3m^3/s

(2) Design and Construction of Diversion Work

Table 2 lists the examples of diversion works for raising construction of the existing concrete dams. The design discharge of a diversion work is the same to the design flood discharge when a concerned existing dam’s flood control function is to be secured. When safety for reconstruction is to be secured, the design discharge is set as the flood discharge of approximately once per a year probability. Based on the relationship between the design discharge and the actual discharge of existing diversion works, the diversion works of the raising reconstruction dams can be classified into the following cases: to utilize existing diversion work; to construct a new diversion work; and to combine existing diversion work and a new diversion work to be constructed.

As the management condition of an existing dam and the reservoir during construction period greatly affect the construction schedule, it is important to set up constraints at an early preparation stage of the construction plan, secure safety for construction work and the downstream region, and establish the construction plan that may shorten the construction period. In addition, if a concerned discharge facility is to be utilized as a diversion work for cost saving purpose, it would be possible that a risk of possible damage to construction work or a risk of possible delay of the construction schedule caused by unexpected amount of flood discharge become greater. Thus, a comprehensive examination should be conducted.

(3) Design of Dam Foundation

When designing dam foundation for raising existing dam, record and measured data for the existing dam construction period is often scarce. Boring surveys are, therefore, conducted for the foundation of the existing dam as well as for the new dam.

As for the evaluation of dam foundations, it is necessary to conduct the evaluation of the original dam and the new raising dam on the equality. As for the design of foundation treatment, the seepage condition in the existing original dam foundation from the reservoir should be evaluated hydro-geologically. And the conformity of the foundation treatment of a new dam to that of the original dam, which is continuity, boundary of construction work, improvement target and so on, should be considered.

(4) Design of Raising Dam Body

The methods of cross section design of existing concrete dam for raising modification and the methods of thermal stress analyses are listed in Table 3. As for the design of cross sections of a dam body, the design method by Kakitani[4] and the finite element method (FEM) are used beyond the ordinary design method.

The evaluation of shear strengths and deformation characteristics of the original and new dam foundations and the evaluation of the structural stabilities of the original and new dam bodies is important for the design of dam body cross sections. If the deformation capability of the new dam foundations is different from that of the original dam, it is necessary to confirm the stabilities of joints between the original and new dam bodies and foundations using FEM analyses in addition to the design method using Kakitani equation. Further, in order to secure structural stabilities of dam bodies, it is important to confirm the uniformity of the original and new dam bodies by evaluating the thermal stresses acting on the boundary of the concrete of the original and new dam bodies. As shown in Table 3, when conducting the thermal stress analyses by taking into account the concrete placing schedule, it is necessary to pay attention to the effects of the thermal contraction of the new dam body to the original dam body, the effects of the external constraints of the original dam body to the new dam body, and especially the effects of the internal constraints of the new dam body due to lift thickness and lift schedule.

Table 3 Design and Analysis Methods of Raising Concrete Dams

Name of Dam	Design Method of Cross Sections			Thermal Stress Analysis		
				Analysis Method		
	Ordinary Method	Kakitani Equation	FEM	Restraint Matrix Method	FEM	Considered Construction Schedule
Shin Maruyama	✔		✔		✔	✔
Shin Katsurazawa		✔	✔		✔	✔
Shin Nakano		✔	✔	✔	✔	✔
Kayaze		✔			✔	✔
Hikawa	✔				✔	✔
Yasugawa	✔				✔	✔
Kuroda	✔				✔	✔
Magaribuchi	✔		✔		✔	✔
Mitaka		✔	✔		✔	✔
Nagara		✔			Not examined	
Shin pogawa		✔	✔			
Shimonohara		✔			✔	
Sakamoto		✔			✔	✔

Appendix, Kikitani Equation,

The Kakitani equation is a design theory used for raising concrete dam. In this equation, new and original concrete after raising construction of dam is treated as a complete one rigid mass without regarding the volume change of the new concrete during the hardening period and the difference of the physical properties of the original concrete with those of the new one .

(5) Excavation of Dam Foundation

When conducting foundation excavation works for a raising dam, blast excavation works are restricted for most of dams. No blast excavation work is normally used within 5m from the original dam. When blast excavation work is to be conducted, allowable values of blast vibration are regulated and monitoring of the vibrations is conducted for the protection of the original dam body.

It is necessary to further study how to decide the restriction values of the blast vibration and how to chose the foundation excavation method; blast excavation method or not.

(6) Concrete Work of Dam Body

As the unification method of original and new dam concrete, pitching of the original dam surfaces and placing of bed mortar are normally used for most of dam raising work. However, reinforcing steel bars and anchor bars were not regularly used for unification of original and new dam concrete. The use of reinforcing steel bars and anchor bars was decided upon based on

Table 4 List of Researched Raising Embankment Dams

Name of Dam	Projecte Agency	Dam Purpose	Dam Type	Year Completed	Raising Work	Dam Height (m)		Location Raised
						Original	Modified	
Ohkawa	Naze City	AW	R	1990	1971～1981	33.7	49.2	b) Up&Down.
Ohtaniuti	Hokuriku Agri Bureau	A	E	1954	1975～1990	15.0	23.2	a) Downstream
Fukuti	Okinawa Dev. Agency	FNWI	R	1974	1978～1990	91.5	91.7	
Shirakawa	Nara Prefecture	A→FA	E	1933	1971～1996	27.6	30.0	a) Downstream
Nagaike	Saga Prefecture	A→FA	E→R	16XX	1992～1996	17.0	34.8	a) Downstream
Kurahasi	Nara Prefecture	A→FA	E	1956	1987～2000	31.0	36.5	b) Up&Down.
Sannokai	Tohoku Agri. Bureau	A	E→R	1953	1990～2001	37.4	61.5	a) Downstream
Sayamaike	Osaka Municipal	N→FN	E	616	1980～2001	15.0	18.5	b) Up&Down.
Syukunosawa	Miyagi Prefecture	A	E	1963	1977～2003	18.6	26.0	b) Up&Down.

Purpose: F: Flood Control, N: Multipurpose Use, A: Irrigation, W: Drinking, I: Industry Use, P: Hydropower
Dam Type: G: Concrete Gravity, R: Rock Fill, E: Earth A: Arch

the results of the thermal stress analysis in some dams.

There are cases such that cracks occurred in concrete with the progress of concrete placing work. Thus, it is important to decide a measure prior to start construction work how to deal with cracks if cracks occur under construction.

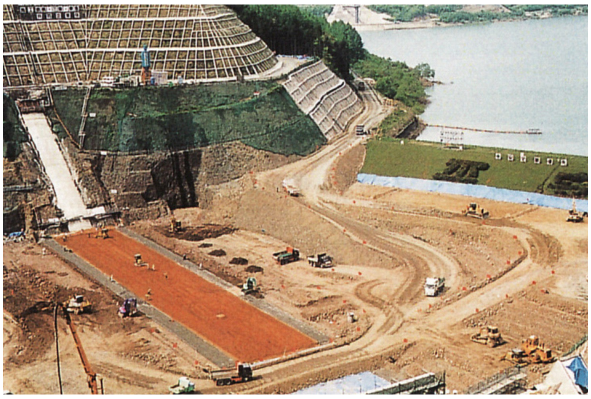
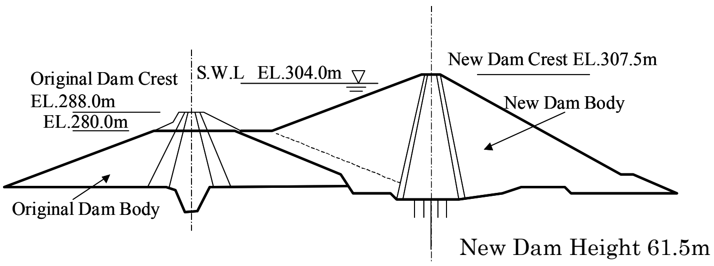


Photo 2 Raising Work of Embankment Dam (Sannokai Dam) [5]

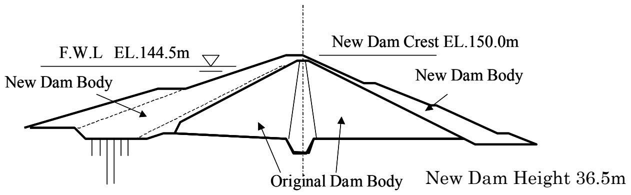
4. Embankment Dams

(1) Research Objective Dams

Table 4 lists the examples of embankment dams whose heights were raised. Figure 2 shows two cases to raise the dam heights as follows; a) to raise the height on the downstream side of the original dam and b) to raise the height on the upstream and downstream side of the original dam with the same dam axis. For case a), construction work can be conducted without emptying the reservoir. For case b), the reservoir must be emptied when embankment work on the upstream side is being carried out. As an example of case a), Photo 2 shows the raising construction work of Sannokai Dam.



a) Raised on the downstream side (Sannokai Dam)



b) Raised on the upstream and downstream side (Kurahashi Dam)

Fig. 2 Example of Raising Embankment Dams

Table 5 Diversion Method and Design Discharge for Raising Embankment Dams

Name of Dam	Diversion Method	Design Discharge
Kurahashi	New diversion tunnel was constructed in base rock foundation.	New design flood discharge: Q=8m^3/s, 1/20-year probability
Nagaike	a) Diversion tunnel in base rock foundatin.	1/10-year probability
Sannokai	a) Existing flood discharge tunnel b) New diversion tunnel	Max flood discharge after modification of original spillway; Q=271m^3/s
Ohtaniuchi	a) Existing intake facility (culvert) b) New spillway	New design flood discharge: Q=7.9m^3/s
Sayamaike	Open channel and box culvert to divert to existing spillway	Existing spillway discharge capacity: Q=223m^3/s
Ohkawa	Existing low-water discharge facility	1/2-year probability, Q=11m^3/s

(2) Design and Construction of Diversion Work

Table 5 lists the diversion works of existing embankment dams whose heights were raised. Basic concept for the design discharge of embankment dams for raising is the same to that of concrete dams. Design flood discharge under construction is applied the flood discharge for 1/10-year to 1/20-year probability and becomes larger than concrete dams.

As for the diversion work plan for an embankment dam, it is necessary to clarify constraints for reservoir management at an early planning stage and establish measures for them.

(3) Survey on Existing Dams

When the height of an embankment dam is to be raised, detailed surveys are conducted not only on the dam foundation but also on the materials of the original dam body. In particular, when a new embankment dam is constructed on an original dam for raising, settlement and deformation of the original dam due to additional loading often cause problems.

To accurately estimate the deformation characteristics of the embankment dam, laboratory deformation tests of large-size specimens using undisturbed samples and in-situ deformation tests would be necessary. The improvement of surveys and test methods is needed in the future.

(4) Design of Dam Foundation

For the foundation design of an embankment dam whose height is to be raised on the same dam axis, properties of the original dam's foundation including permeability are surveyed.

When the hydro-geologically of the dam foundation is to be evaluated, it is important to evaluate the seepage including actual seepage of the existing embankment dam foundation, as the same as for a concrete dam.

(5) Design of Raising Dam Body

As for the design of the cross sections of an embankment dam, its standard dam shape is determined by the circular arch sliding method using the seismic coefficient method. As for embankment dams having considerable issues such as the deformation of the original dam bodies, treatment of the foundations, and an excess pore water pressure in the original dam bodies, the stability of the dam bodies are confirmed using FEM analysis.

As for the design of the dam body whose height is to be raised, it is important to evaluate the difference in the deformation characteristics of the original and new dam bodies. In particular, for the boundary between the original and new dam bodies, it is necessary to take into consideration the deformation characteristics of the original dam body that has been consolidated for a long time

(6) Excavation of Dam Foundation

As for excavation work for a dam foundation in the vicinity of the original dam, blasting work is regulated and excavation without blasting is

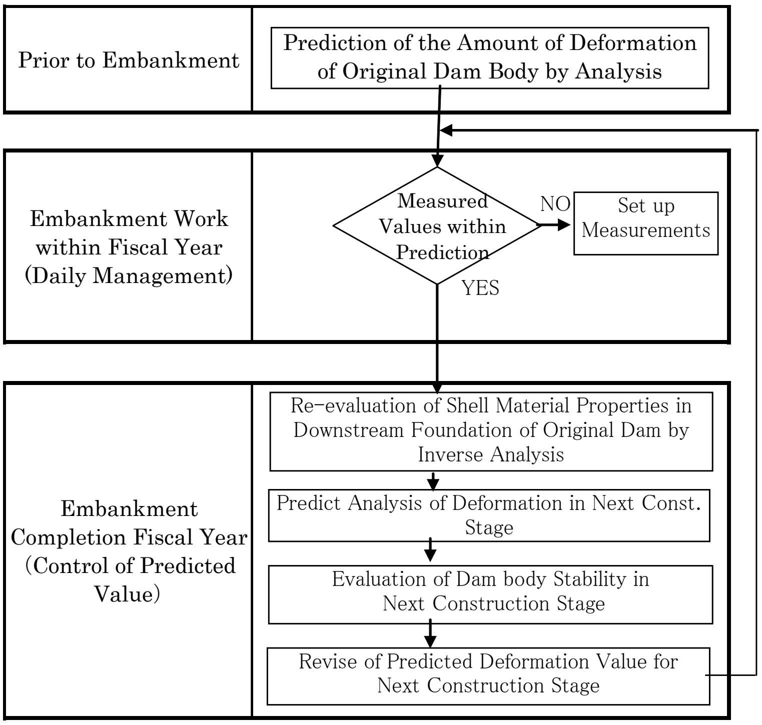


Fig. 3 Execution utilizing information in Embankment Work for Raising (Sannokai Dam) [6)]

carefully conducted.

Through the measure deformation of the original dam body under excavating and excavation works by the utilization of the information based on the inverse analyses with the deformation of dam body, it is necessary to confirm the stability of the dam body and improve the construction method. When conducting blast excavation work for a dam body foundation, it is necessary to pay attention to the effects of vibration to the original dam body.

(7) Embankment Work of Dam Body

The surface layer of the original dam is excavated and removed for most of embankment dams, in the case that a new embankment dam constructs upon an original dam body,.

When a new embankment extensively covers the original dam body, there is a possibility of large deformation of the original dam body with the progress of embankment work. It is, therefore, necessary to upgrade the embankment construction method by monitoring the deformation of the original dam body and proceeding embankment work according to the information estimated by the inverse analysis that corresponds to the deformation. Figure3 shows the flow chart of the execution utilizing information in embankment work at Sannokai Dam.

(8) Foundation Treatment Work

The method of grouting treatment works for raising the height of an embankment dam is basically the same to that for a new dam construction.

When grouting is conducted under an existing dam reservoir filled condition, there are concerns of the grout materials being washed away by seepage water with high pressure and velocity. Therefore, continuous seepage sealing function may not be secured. If the possibility of unsecured seepage sealing is assumed, it is necessary to consider the use of fast hardening grout material.

(9) Appurtenant Works

There are various cases of the design of inlet and outlet works associated with existing embankment dams to be raised, such as modification of existing facilities, construction of new facilities, or combined use of existing and new facilities.

As for dams with small scale height raising works, it is good for the utilization of existing spillways and intake facilities as much as possible. When planning of arrangement of spillways and intake facilities, it is necessary to examine the effective use of existing facilities by taking into consideration of the topography and geological conditions of the dam site. When determining the location of a new dam body for raising, it is required to comprehensively consider the arrangement of the spillway and intake facilities as well.

5. Conclusions

The research results are summarized as follows:

1) Safe and rational diversion works should be planned at an early planning stage by clarifying possible constraints for dam functions and reservoir management during a construction period.
2) Examination of the hydro-geological condition at a dam foundation should be conducted, including the research of seepage from the existing reservoir, in the case of design of foundation treatment.
3) When designing the body of a concrete dam to be raised, it is important of the evaluation of the uniformity of the original and new dam bodies.
4) For the placement of dam body concrete, it is important to determine how measurements, in advance, to be taken against cracks that may occur under construction.
5) For the survey of the bodies of embankment dams to be raised, it is necessary to upgrade the study and test methods in order to accurately research the deformation characteristics of the original dam body.
6) For the design of the bodies of an embankment dam to be raised, it is important to examine the difference in deformation characteristics of the original and new dam bodies.
7) For the raising work of an embankment dam, it is necessary to upgrade construction work, by means of monitoring the deformation of the dam body during embankment work and confirming the safety of the dam body by executing with a full utilization of the monitored information.

The authors expect that the dam refresh technologies summed up by the JCOLD subcommittee will be fully utilized for further study and construction technology development.

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