SECUREMENT OF SAFETY AND ENHANCEMENT OF VALUE FOR THE AGED DAMS IN SOUTH KOREA

SEUNGHEE DO
General Manager, Korea Hydro & Nuclear Power Co. Ltd., South Korea

JINSEOB YOON
Senior Manager, Korea Hydro & Nuclear Power Co. Ltd., South Korea

RAECHANG PARK
Manager, Korea Hydro & Nuclear Power Co. Ltd., South Korea

INSIK LEE
Executive Vice President, Korea Hydro & Nuclear Power Co. Ltd., South Korea

1. INTRODUCTION

1.1 Overview

The hydro power generation dams in Korea were mostly constructed in 1930s~1960s, but the dams constructed then have now been aged to cause problems, such as a lack of safety, an increase in maintenance costs, etc., which are expected to enlarge more in the future.

In order to be sustainable, the hydro power generation dams will have to satisfy the social amenities needs as well as secure the safety and economic usefulness for the natural environments having changed recently as a huge artificial structure.

The Korea Hydro & Nuclear Power Co., Ltd. has promoted synthetic repairs and reinforcement based on a securement of safety and an enhancement of value, with the Cheongpyeong Dam(completed in 1943), one of the oldest dams in Korea, as an example, in order to increase the physical and social value of the aged dams possessed.

1.2 Current situation of the cheongpyeong dam

1.2.1 *Overview of The Cheongpyeong Dam*

The Cheongpyeong dam is a gravitational concrete power generation dam of 31.0m height and 407.0m length with 24 floodgates, with a view to generating electric power using a head between the upstream and the downstream, which plays a role of controlling the flooding amount in case of a flood together with the upstream reservoir. The Cheongpyeong hydro power plant completed the construction of its unit 1 in July 1943 and its unit 2 in October 1943 to be handed over to our country along with our liberation as the Hangang Hydroelectricity Co., Ltd. started the construction of dams of 185 million tons at the downstream of Bukhan River in order to develop electric power from the Han River water system in August 1939 under Japanese imperialism, and completed the construction of its unit 3 in April 1968 and its unit 4 on 15th December 2011, to play an important role based on the electric power system as a power plant with the biggest power generation capacity among the general hydro power plants in the Bukhan River water system by having a power generation capacity of 139.6 MW.

Table 1 . Cheongpyeong dam general

Division		Specification	Division		Specification
Reservoir	Dam location	Gapyeong-gun, Gyeonggi-do, Korea	Spillway	Type	Adjustable (floodgate, gate leaf) type
	Effective water storage capacity	82.6 million m^3		Maximum outflow	20,736 m^3/s
	Planned flooding level	EL. 52.0 m		Gate leaf	Roller Gate
	Normal full water level	EL. 51.0 m		Size	12.0×10.0×24
Dam	Dam type	Concrete dam-Gravitational	Winch	Type	Wire rope type
	Dam crest elevation	EL. 53.0 m	Highway bridge	Type	RC steel plate compound bridge
				W×L× Quantity	5.5 m × 18.8 m × 25EA
	Dam height	31.0 m	Power generation equipment	Hydraulic turbine type	Vertical shaft Kaplan, vertical shaft propeller
	Dam length	407.0 m		Capacity	79,600 kW
Completion year		1943. 07. 01	Constructor		Hangang Hydroelectricity Co.,

1.2.2 *Cheongpyeong Dam Diagnosis Background and Result*

As the importance of safety checkup and maintenance for facilities in our country came to be recognized due to a series of safety accidents in large public facilities(collapse of Changseon bridge, Seongsu bridge, Sampoong Department Store, etc.) generated since 1990, so in order to improve this situation fundamentally, the「special law regarding the management of safety for facilities」was established including the contents of bringing up a reliable professional institution that can systemize the work on the safety checkup and maintenance of facilities, give the duty and responsibility of maintenance to the facility administrator, and execute this professionally.

Therefore, our company periodically conducted a precise safety diagnosis service to investigate the physical and functional defects of the Cheongpyeong dam, a class 1 facility according to the above law, Article 7, analyze its structural safety and damage status clearly, and take a proper measure, as whose result, the Cheongpyeong dam requires the overall cross-sectional repairs rather than local repairs due to an increase in the period of common use of the dam as 70 years have passed since completed, and has aged generally, but secures the safety of the dam, so as to be judged as class C, and thus was evaluated as needing a long-term measure against aging in the future.

2. MAIN DISCOURSE

2.1 Investigation of The Current Situation of Dams

In order to increase the physical and social value of the aged dams, this study investigated the elapsed years, type and safety class of the 21 dams possessed by our company and analyzed the current situation of them, as whose result, 5 hydraulic dams among 8 dams have exceeded 50 years of economic lifespan, so as to be judged as needing a medium- and long-term measure for safety and maintenance.

Table 1 : Elapsed years and safety class of hydraulic dams

Hydraulic dam	**Hwa cheon**	**Chun cheon**	**Euiam**	**Cheong pyeong**	**Pal dang**	**Goe san**	**Bo seong**	**Do am**
Completion	1944	1964	1967	1943	1972	1957	1935	1990
Dam type	Concrete	Concrete	Concrete	Concrete	Concrete	Concrete	Concrete Fill dam	Fill dam
Safety class	C	C	C	C	C	C	C	B

Table 3 : Elapsed years and safety class of pumped storage dams

Pumped storage dam	**Cheong pyeong**	**Sam rangjin**	**Muju**	**San cheong**	**Yang yang**	**Cheong song**	**Ye cheon**
Completion	1980	1985	1995	2002	2006	2007	2011
Dam type	Fill dam	Fill dam	Fill dam	Fill dam	Fill/con`c dam	Fill dam	Fill dam
Safety class (Upper/lower)	C	C/C	C/C	B/B	B/B	B/B	B/B

2.2 Reality and Problem in Dam Maintenance

Recently, throughout the world, large-scale heavy rains are not only frequently taking place due to weather accidents such as EI Nino and La Nina, but much damage to human life and property is also taking place due to large-scale earthquakes, etc. that took place all over the world. In our country, large-scale heavy rains are also frequently taking place such as typhoon Rusa in 2002 and typhoon Maemi in 2003, and many earthquakes also took place historically and several earthquakes also took place recently, so our country has turned out to be not a safe zone for earthquakes. An emergency situation such as a collapse of dam bodies can not only be generated by the natural phenomenon such as these large-scale heavy rains or earthquakes, but an unexpected emergency situation can also be caused by the occurrence of defects in dam bodies and accessory structures due to aging of structures related to dams when a long time has passed since construction of the dam. Therefore, the synthetic review on the safety of dam facilities against extreme natural disasters, a future risk factor, as above is still insufficient.

In addition, the scale, time and cost of repair/reinforcement are gradually being increased as shown in <Table 4 > below by performing re-repairs repeatedly after a certain period has passed through a local and holding-level repair of the confirmed defects according to the result of safety checkups and precise safety diagnoses for our company's dams, but the utility of repairs and reinforcement is being decreased because the establishment of a synthetic measure considering the elapsed years, repair scale and part of the facilities is still insufficient.

Table 4 : Amount of money required for the repair and reinforcement of dam structures pursuant to the result of precise safety diagnoses (Unit: US$)

Division	1st diagnosis	2nd diagnosis	3rd diagnosis	4th diagnosis
Goesan	100,000	33,000	308,000	16,000
Paldang	25,000	17,000	58,000	408,000
Euiam	33,000	17,000	191,000	508,000
Cheongpyeong	233,000	66,000	58,000	**1,416,000**

※ Geosan dam : Large-scale reinforcement work was performed after the 3rd diagnosis had finished ('12 ~'13)

Finally, our company has been doing management such as maintenance focused on only the unique function of the existing dams so far in fact although the number of aged dams is continuously increasing recently. As a result, there has been a lack of efforts to enhance the social value such as reinforcement of views through organic connection with the surrounding areas, improvement of the image of aged dams, etc.

2.3 Aged Dam Improvement Plan

2.3.1 *Enhancement Of The Safety And Physical Value Of Aged Dams*

We have experienced through various events in the past that an unexpected emergency situation can be caused by the occurrence of defects in the aged dam structures due to a natural phenomenon such as large-scale heavy rains and earthquakes recently. Accordingly, this study aims to review the securement of safety and the enhancement of physical value for the dam bodies and accessory facilities through a synthetic review on the safety of aged dams against extreme natural disasters, a future risk factor.

First of all, the basic types of natural disasters include extreme flooding, multiple disasters (flooding + landslide), extreme earthquakes, etc. The result of reviewing the risk of Cheongpyeong dam against 3 kinds of natural disasters is as follows:

- Extreme flooding : All the dams are judged to secure safety as a result of evaluating the hydrological safety of dams against the possible maximum flooding(PMF) during a precise safety diagnosis for the dams.
- Multiple disasters : The risk level of dams against landslides is separately being reviewed through a service project, etc.
- Extreme earthquake : As a result of a precise safety diagnosis, the body of concrete dams(including composite dams) is safe against extreme earthquakes, but the axial resistance of their pier part to earthquakes is evaluated as a little insufficient.

As a result of investigating the domestic and foreign examples because it is judged as necessary to secure the axial resistance of the dam pier part to earthquakes which is evaluated as a little insufficient against extreme earthquakes among the above 3 kinds of results, there were earthquake force attenuation methods such as installation of a damper at the lower pier of a highway bridge, installation of struts between the dam piers, and application of a highway bridge support as a vibration isolation support; and a result of analyzing their features, the installation of a damper and the installation of struts were investigated to have a high earthquake force attenuation ratio but require a high cost, and the application of a vibration isolation support was investigated to require a less cost but have no big earthquake force attenuation ratio, so it is thought as necessary to apply a reinforcement plan through an analysis depending on the deficiency degree of resistance to earthquakes by dams.

① Installation of a damper at the dam pier	② Installation of struts between dam piers	③ Application of a vibration isolation support

Fig. 1 : Domestic and foreign examples of securing the resistance of dam pier parts to earthquakes

As a result of applying the safety analysis and stress safety degree of the overflow part against earthquakes to a dam safety class simulation for evaluating a virtual safety class by analyzing the earthquake related factors affecting the determination of a safety class to check whether the safety of a dam was improved or not through reinforcing the axial resistance to earthquakes by dams as above, the possibility that the safety class could be enhanced was confirmed.

Thus, this study aims to evaluate the expected remaining lifespan according to it when the safety class of a dam is enhanced, review its extension plan, and then analyze its effect on the extension of the expected lifespan. As a result of investigating the domestic and foreign data on the method to evaluate the expected remaining lifespan of a dam, the data on the research results, evaluation methods, etc. appeared to be insufficient; and as a result of estimating the increased years of the expected lifespan of a dam according to a statistical method by improving the safety evaluation score, with Cheongpyeong dam as an example, by preparing a "curve of the dam safety evaluation score versus the elapsed years of aging" using the data on the elapsed years and safety evaluation result of domestic dams to establish a dam's remaining lifespan evaluation plan, the expected lifespan of a dam was estimated as increasing.

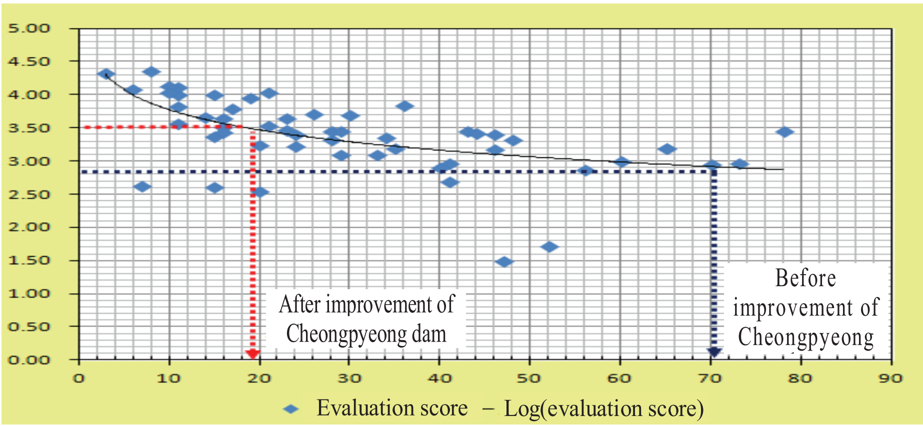


Fig. 2 : A curve of the dam safety evaluation score versus the elapsed years of aging

As a result of reviewing various plans to enhance the safety and physical value of our company's aged dams and analyzing the plans by applying them to the Cheongpyeong dam as an example, the application of a vibration isolation support to a dam management bridge is judged as being able to secure the axial resistance of the dam pier to earthquakes according to the seismic analysis result; and as a result of virtually evaluating the derivation, repair and reinforcement completion status of major defects(axial resistance of the dam management bridge, winding tower and pier to earthquakes, etc.) affecting the enhancement of classes through a dam safety class simulation, the total score was evaluated as 3.59, class B, to increase the total safety class also by 1 step(C→B), so it is judged that it can secure the safety of an aged them. And, as a result of comparing the elapsed years of aging for the current Cheongpyeong dam(about 70 years) and the elapsed years of aging after completion of repairs and reinforcement(about 20 years) according to the safety class evaluation score using a "curve of the dam safety evaluation score versus the elapsed years of aging" depending on the upgrading of safety classes, about 50 years of extension of the expected lifespan of a dam can be estimated to increase the physical value of the dam as well.

2.3.2 *Reduction of the Aged Dam Management Cost*

It is thought that it will be also necessary to secure a proper economic efficiency to maintain an aged dam continuously in the future although it is important to secure the safety of our company's aged dam whose number is increasing. Thus, it is necessary to establish an optimal repair and reinforcement plan considering the investigation and excavation of advanced methods, economic efficiency, life cycle costs, etc., so this study aims to review the plan pursuant to it.

As a result of investigate the usual existing concrete dam cross-section repairing methods and examples, the above-ground part mainly used a thin repair in a 10~40mm thick plastering and spraying method using a cross-section restoration material(cross-section recovery mortal), was high in repair costs, was difficult to manage in quality, and showed problems such as birdcaging, cracks, efflorescence, etc. due to various causes such as chemical and mechanical mechanism, bad construction, etc. after a repair.

So, a deep repair method of 100mm thickness reinforced with anchors and rebars was presented during the previous precise safety diagnosis to complement the disadvantage of thin repairs using the existing cross-section restoration material, but as a result of reviewing the plan for a difficulty in securing quality, an increase in construction costs, etc. due to the characteristics of cross-section restoration materials when constructing a broad area, it is judged that the utilization of a general reinforced concrete method using molds and rebars can secure quality and reduce construction costs a lot to reduce the basic costs.

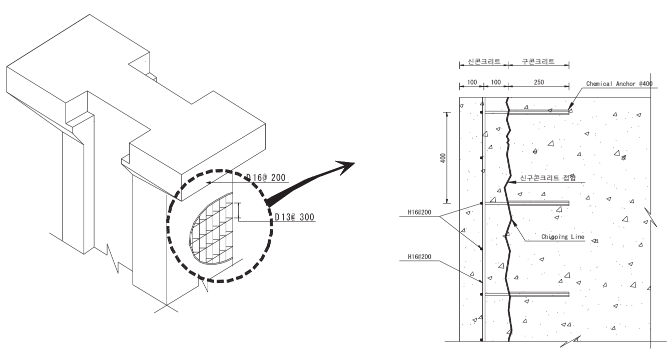
Table 5 : Concrete cross-section repairing method comparison table

Applicable method	**General reinforced concrete**	**Cross-section restoration material (cross-section recovery mortar)**
Applicable part	Overall repair part	Local repair part
Method overview	• Chip the repair part deeply to form a t=150 mm or more restored cross-section. • Install a mold, rebar and anchor, and place general concrete.	• Chip the repair part thinly to form a t = 10~40 mm restored cross-section. • Place the cross-section restoration mortar through plastering or spraying.
Construction cost	380 thousand KRW/㎡(t=100 mm)	529 thousand KRW/㎡(t=100 mm, average unit price)
Feature	• Easy to control in quality through installation of a mold • Favorable economic efficiency	• Suitable for a local repair in which it is difficult to install a mold.

In addition, as a result of reviewing the life cycle costs and the applicability to the related dam maintenance as mentioned before, in order to apply the VE to the dam maintenance, the exact LCC analysis of dam facilities is necessary, which requires the definition of common lifespan for the object facilities and the reliable research results on the period and cost of maintenance. The dam facility is an integrated facility of various subsidiary facilities such as dam bodies, spillways, dam management bridges, water intake facilities, etc., and it is judged as difficult to apply a quantitative LCC concept to the maintenance of dam facilities due to a lack of domestic and foreign LCC analysis research data on the current dam facilities, but for the dam management bridge, it is thought that it will be possible to derive an optimal plan such as repairs, reinforcement, reconstruction, etc. through a LCC analysis by referring to the research results on the LCC of bridges executed in the road construction, etc.

Therefore, as a result of applying the above mentioned method for reduction of the aged dam management cost, etc. to the Cheongpyeong dam as an example, the application of a general reinforced concrete method as a repair plan for the overall repair part such as a winding tower, etc. could secure quality and minimize occurrence of defects after maintenance and reduce the construction costs by about 36% compared to the existing methods(cross-section restoration material method), and it is thought that the application of this method to other aged dams will be able to reduce costs a lot in the future.

Front view for the damaged part of a winding tower



Schematic diagram for repairs

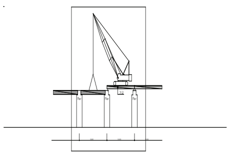
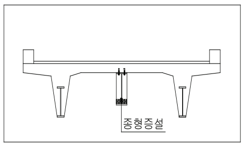
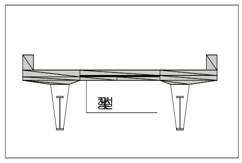
Fig. 3 : Schematic diagram for repairs using general reinforced concrete

Table 6 : Construction cost saving amount pursuant to the application of an improved method (Unit: US$)

Division	**Cross-section restoration material method (Method presented by the previous safety diagnosis)**	**General reinforced concrete method (Improved method)**	**Saving amount**
Construction cost	691,000	**441,000**	250,000 (36%)

In addition, for the highway bridge for Cheongpyeong dam, the construction cost could be reduced by about 5,300 million KRW(54%) compared to the method presented by the previous precise safety diagnosis by reconstructing the upper structure using a launching girder method, an optimal plan, through the investigation, application and LCC analysis of the new method in order to establish an optimal reinforcement plan having economic efficiency, as it was judged as class D due to lack of load carry capacity and aging of facilities as a result of the previous precise safety diagnosis to need overall reinforcement or reconstruction.

Table 7 : Comparison by the dam management bridge reinforcement or reconstruction plans (Unit: US$)

Division	Method presented by the previous precise safety diagnosis		Method reviewed at this time	
	Reconstruction (Temporary bridge + crane)	Reinforcement (Bell type extension)	**Reconstruction (Launching girder method)**	Reinforcement (Slab replacement)
Schematic diagram				
Bridge class	Class 1 (DB-24)	Class 2 (DB-18)	Class 1 (DB-24)	Class 2 (DB-18)
Construction cost	816,000	333,000	**374,850**	416,000
LCC	883,000	533,000	**442,000**	616,000
Review result	The reconstruction using the launching girder method is accompanied by a little larger initial construction cost compared to the bell type extension reinforcement method, but is generally favorable in the life cycle cost(LCC), constructability, future usability, etc. considering the lifespan of the bridge.			

2.3.3 *Enhancement of the Social Value of an aged Dam*

As a result of investigating the examples of dam scenery improvement, tourism merchandizing, corporate communication, etc. with a view to enhancing the social value such as enhancement of prospects, improvement of the image of aged dams, etc. through organic connection with the surrounding areas, there was painting of dam bodies, relief, installation of scenery lighting, etc. as an example, and there was construction of beams on the outer wall of the buildings, installation of symbolic sculptures, etc. as an example of corporate communication. As a result of reviewing the applicability and efficiency of our company's aged dams based on the above examples, it is judged that the improvement of scenery can be applied first to the dams with a high expectation effect(dams in the Bukhan River system) by considering the geographical location, importance, floating population, etc. of a dam, and the painting, scenery lighting, symbolic sculpture installation, etc. requires a lot of expenses and is difficult to maintain, and the relief is judged to be difficult to apply to our company's dams, most of which is a overflow part, so it is necessary to review an economical and maintainable dam scenery improvement plan using color-exposed concrete, patterned molds, etc. during concrete work to repair the dam cross-section as an alternative. The social value of aged dams could be enhanced in a direction of being able to enhance the prospects and improve the image of aged dams by applying color-exposed concrete and patterned molds to the winding tower of the Cheongpyeong dam, applying 2 art walls to the auditorium building of the left bank and the winding tower of the right bank, and composing a viewing space at the downstream part of the dam.

Color-exposed concrete at the winding tower	Art wall at the auditorium building of the left bank	Viewing space at the downstream part of the dam

Fig. 4 : Expected view of Cheongpyeong dam improvement

3. CONCLUSION

The Korea Hydro & Nuclear Power Co., Ltd. has promoted the synthetic repair and reinforcement of the Cheongpyeong dam(completed in 1943), one of the oldest dams, as an example, based on the securement of safety and the enhancement of value, in order to increase the physical, economic and social value of the aged dams possessed by it.

Firstly, enhancement of the safety and physical value of a dam.

As a result of virtually evaluating the repair and reinforcement completion status of major defects(axial resistance of the dam management bridge, winding tower and pier to earthquakes, etc.) affecting the upgrading of safety classes through a dam safety class simulation, the synthetic safety class was upgraded by 1 step(C→B) to secure the safety of aged dams; and as a result of evaluation using a "curve of the dam safety evaluation score versus the elapsed years of aging" depending on the upgrading of safety classes, the comparison of the elapsed years of aging for the current Cheongpyeong dam(about 70 years) and the elapsed years of aging after completion of repairs and reinforcement(about 20 years) shows an extension of lifespan expectancy of the dam by about 50 years, so as to be expected to increase the physical value of them as well.

Secondly, reduction of aged dam management costs

The replacement with a general reinforced concrete method as a plan to repair the overall repair part such as winding towers, etc. could secure quality and reduce the construction cost by 36% compared to the existing methods(cross-section restoration material method); and for the highway bridge of the Cheongpyeong dam, the construction cost could be reduced by about 5.5 billion KRW(54%) compared to the method presented by the previous precise safety diagnosis by applying a launching girder method, an optimal plan, through the investigation, application and LCC analysis of the new method. This was enabled through the establishment of a proper management plan considering the past repair/reinforcement analysis, previous example investigation and life cycle cost (LCC), through which the economic efficiency could also be secured.

Thirdly, enhancement of the social value of aged dams

The social value of aged dams was enhanced in a direction of being able to reinforce the prospects and improve the image of aged dams through organic connection with the surrounding areas although considering the efficiency and sublating the plans requiring an excessive cost and having a difficulty in maintenance when improving the scenery by considering the geographical location, importance, floating population, etc. of the dam.

Based on the synthetic repair and reinforcement plan for the Cheongpyeong dam, the dam life cycle cost was reduced compared to the existing holding-type repair and reinforcement, while the physical and social value such as an increase of safety, an extension of lifespan expectancy, an improvement of scenery, etc. was increased. This result will be not only a good precedent of maintenance for the aged dams possessed by our company, but also a new paradigm for the management of the aged dams to be executed in the future.

ACKNOWLEDGEMENTS

The authors would like to express their gratitude for the extensive cooperation provided by Cheongpyeong Hydro Power Plant.

REFERENCES

[1] MOLIT , 1994, Dam facility maintenance and management standard

[2] Korea Water Resources Association, 2011, River design standard and dam design standard

[3] Korea Expressway Corporation, 2005, A study on the preventive maintenance and management plan for bridges

[4] KISTEC, 2012, A study on the plan to extend the common lifespan of road bridges

[5] KISTEC, 2010, Detailed guideline for safety checkups and precise safety diagnoses