SEISMIC PERFORMANCE EVALUATION OF DAM APPURTENANT FACILITIES

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ABSTRACT

In the past, the birthplace of civilization was around rivers to obtain water. Even today, water and electric power are essential for the normal functioning of the city. To this end, dams are constructed to utilize seasonally biased rainfall at desired times, and additionally generate electricity through hydro-power generation. Dams, such as those of significant SOC, must be checked to ensure they are safe from increasing seismic events. In particular, the evaluation of safety of not only dams but also various attached facilities for water supply and hydro power generation has emerged as an important task. For this, the Ministry of Environment and K-water have revised the dam seismic design criteria in January 2019. In this study, seismic performance evaluation was performed, which included all essential dam attached facilities such as spillway, intake tower, water supply tunnel, windlass, electric power station, floodgate. The seismic performance evaluation will be performed for all the dam attached facilities, and K-water will conduct projects by reviewing seismic reinforcement plans for facilities that are considered to have safety problems.

1. PROJECT TITLE / SUBTITLE

Seismic evaluation performance of the dam attached facilities for K-water dams

2. OBJECTIVE OF PROJECT

The purpose of this project is to check the structural safety of seismic evaluation in accordance with the revised dam seismic design standard (2019). As dam attached facilities such as intake towers are added to the seismic evaluation performance targets, seismic performance evaluation should be performed on dam attached facilities to confirm the safety of the facilities. And, the improvement plan should be established according to the evaluation results.

3. SCOPE OF PROJECT

3.1 Project periods

The 10th Jul., 2017 ~ The 16th Dec., 2019 (690 days)

3.2 Target facilities of project

The facilities targeted for this project are the 78 EA(total 117) of the dam attached facilities of 14 dams. The status of facilities are as follows.

Table 1 : Dam attached facilities of 14 dams

ITEMS	Quantity
Spillway	18
Intake tower	6
Intake tower Br.	10
Spillway Br.	9
Waterway Tu.	16
Power plant	5
Gate	19
Hoist	34
Total	117

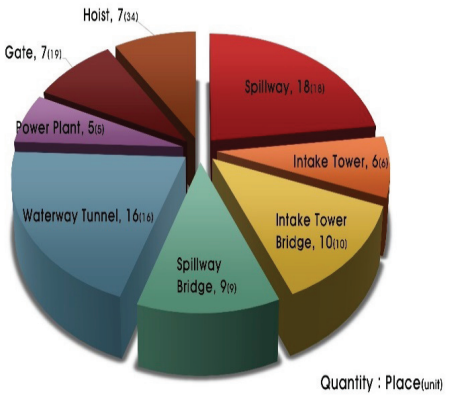
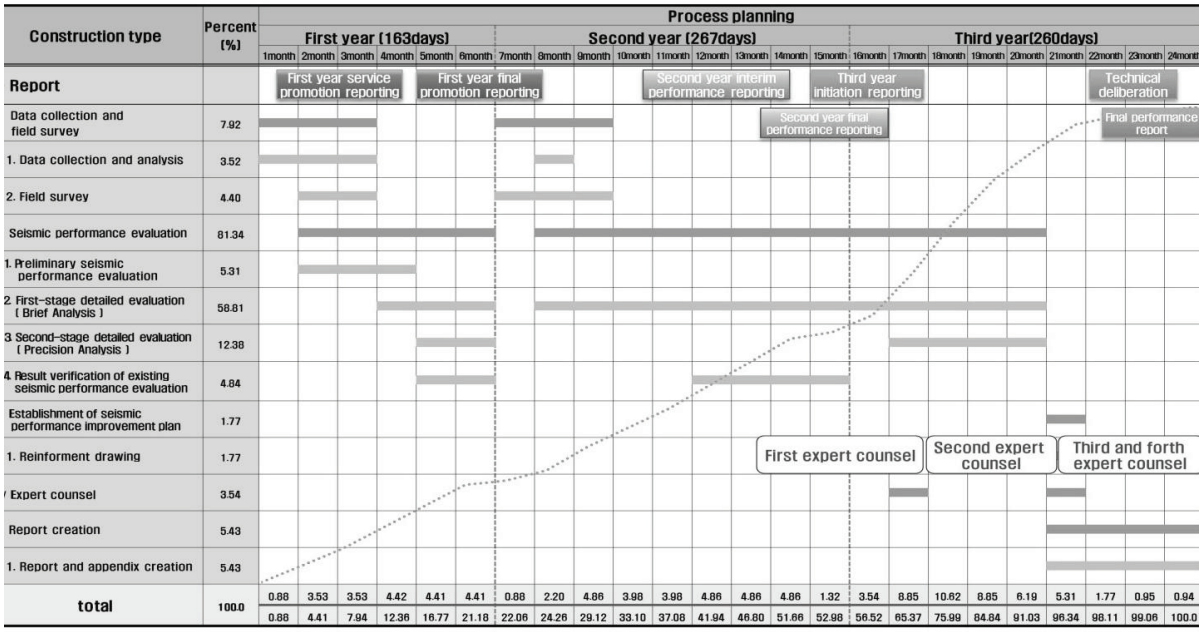


Table 2 : Detailed target facilities status of 14 dams

Dam	Completion year	The nos. of facilities									
		Spill way	Intake tower		Intake Tower Br.	Spillway Br.	Waterway Tunnel	Power plant	Gate	Hoist	Total
			Verifi-cation	Evalu-ation							
Kawang-dong	1989	1	-	-	-	1	1	-	1(4)	1(8)	5
Dal-bang	1990	1	1	-	1	1	1	1	1(2)	1(4)	7
Young-cheon	1980	2	3	-	3	1	2	1	1(3)	1(6)	11
An-gye	1971	1	1	-	-	-	1	1	-	-	3
Gam-po	2006	1	1	1	1	1	1	-	-	-	5
Un-mun	1994	2	2	-	-	2	1	1	2(6)	2(8)	10
Dae-gok	2005	1	1	1	1	1	1	1	1(3)	1(6)	8
Sa-yeon	1965	1	1	-	-	-	-	-	-	-	1
Da-am	1969	2	1	-	-	1	2	-	-	-	5
Sun-am	1964	1	1	1	1	-	1	-	-	-	4
Yeon-cho	1979	1	1	-	-	-	1	-	-	-	2
Gu-cheon	1987	1	1	1	1	-	1	-	-	-	4
Su-eo	1978	2	1	1	1	-	2	-	1(1)	1(2)	8
Pyung-lim	2007	1	1	1	1	1	1	-	-	-	5
Total	-	18	16	6	10	9	16	5	7(19)	7(34)	78

3.3 Work schedule



4. THE CONTENTS OF PROJECT

4.1 Collecting data and field survey

A. In-depth surveys on the target facilities should be conducted to investigate the condition, rehabilitation history, specifications, and site conditions.

B. Design reports, structural reports, construction drawings, construction sites, precision safety diagnosis reports, and other reports on seismic design (evaluation) at the time of construction should be collected to investigate seismic zones, seismic grades, ground conditions, and the presence of seismic design.

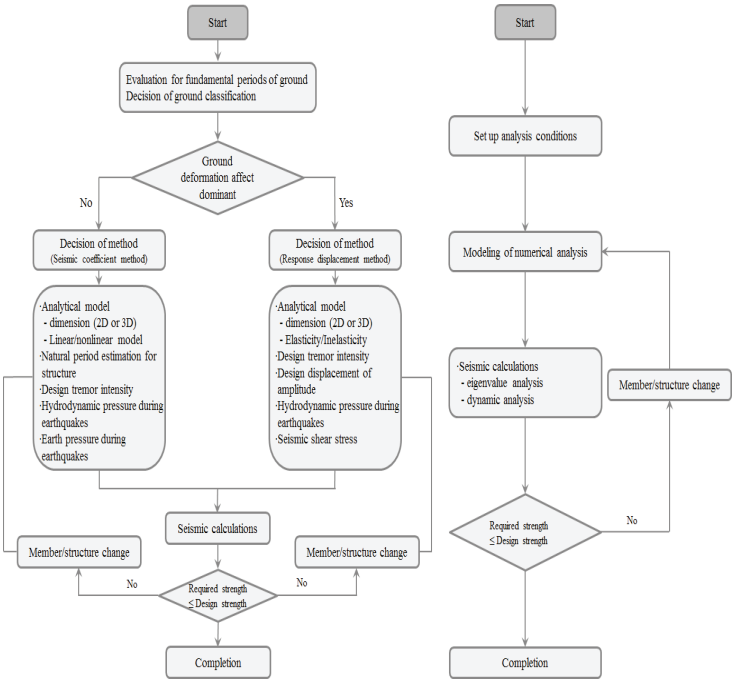
C. Review and reflect the results of seismic performance evaluation performed in the previous task such as "Establishment of facility stabilization plan" and "Yong-su dam safety reinforcement project M/P".
D. If the drawings required for the seismic performance evaluation are insufficient or not computerized, the seismic performance evaluation shall be carried out through field investigation and drawing computerization.
E. Collect and compare the domestic and international seismic evaluation and reinforcement plan data and apply it to this task.
F. Continuously check for changes in the seismic evaluation criteria in progress and apply the latest seismic performance evaluation criteria to this task.

4.2 Establishment of seismic performance evaluation and improvement plan

A. According to the seismic performance evaluation plan established, seismic performance evaluation (preliminary evaluation, precision evaluation) for each facility is carried out.
B. The seismic performance evaluation takes into account the effects between linkages and adjacent facilities (dam, spillway, approaching bridge, sluice, winch, etc.).
C. From the facilities that satisfy the seismic performance (detailed two-stage evaluation results), the maximum design progress (acceleration) to secure safety is calculated by analyzing the seismic performance limit values for each one location by type.
D. As a result of the seismic performance evaluation, the optimal seismic reinforcement method for each detailed facility is proposed in consideration of economic feasibility and construct-ability for facilities where seismic performance should be required.
E. Considering the importance and urgency of facilities, the priority criteria for seismic performance improvement by dam and facility are presented, and annual investment plans are presented.

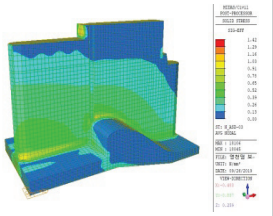
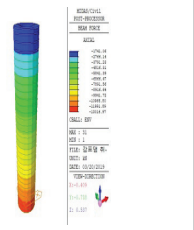
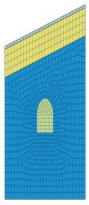
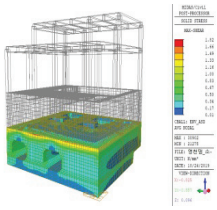
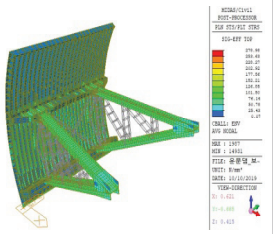
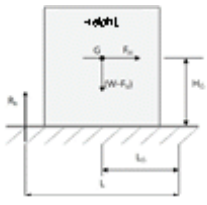
5. SEISMIC EVALUATION PERFORMANCE

5.1 General

Item	Content
Procedure	Preliminary Evaluation → Brief Analysis (Static) → Precision Analysis (Dynamic) → Improvement Plan
Preliminary Evaluation	• As this service is conducted by the client's policy judgment, the following additional investigations are made. ➔ Document whether or not seismic design and seismic performance evaluation were conducted ➔ Check if facilities exist for additional seismic performance evaluation
Estimation of Design Ground Motion	• Establishment of design ground motion of 'NCE level' in accordance with recently revised seismic design general (Ministry of Land, Infrastructure and Transport, 2018) and dam seismic design (Ministry of Environment, 2019) ➔ Design ground acceleration is calculated according to earthquake zone, seismic class of facility and ground classification ➔ Soil classification is classified into S1 ~ S6 considering the depth of bedrock.➔ Classification and application of rock and soil ground according to changes in the standard design response spectrum
Precision Evaluation Flow-chart	

[Brif Analysis Flowchart] [Precision Analysis Flowchart]

5.2 Detailed evaluation of seismic performance for dam auxiliary facilities

Structure	Detailed evaluation performance	Example
Spillway	• Method : Equivalent static analysis(Brief analysis),Time-history analysis(Precision analysis) • Load : Dead load, Water pressure, Seismic load • Main check : Force and stress check (Internal stability)Overturning, Sliding, Bearing capacity (External stability)	
Intake Tower	• Method : Response spectrum analysis (Brief analysis),Time-history analysis (Precision analysis) • Load : Dead load, Water pressure, Seismic load • Main check : Force and stress check (Internal stability) Overturning, Sliding, Bearing Capacity(External stability)	
Intake Tower Br.	• Method : Response spectrum analysis (Brief Analysis),Time-history analysis(Precision Analysis) • Load : Dead load, Seismic load • Main check : Capacity of shoe, Support length, Pier (If necessary)	
Waterway Tunnel	• Method : Response spectrum analysis (Brief analysis),Time-history analysis(Precision analysis) • Load : Dead load, Water pressure, Seismic load • Main check : Stress at lining	
Power Plant	• Method : Response spectrum analysis (Brief analysis),Time-history analysis (Precision analysis) • Load : Dead load, Live load, Water pressure, Seismic load • Main check : Stress and force check formain element(Girder, Pier etc.)	
Gate	• Method : Response spectrum analysis(Brief analysis),Time-history analysis(Precision analysis) • Load : Dead load, Live load, Water pressure, Seismic load • Main check : Stress check for main element(Skin plate)(Capacity/ Demand)	
Hoist	• Method : Pseudo static analysis(Brief analysis) • Load : Dead load(hoist/gate), Seismic load • Main check : Anchored bolt checkOverturning, Sliding of hoist	

6. EVALUATION RESULT

6.1 The seismic class and seismic performance of dam facilities

The seismic class and seismic performance of dam facilities in this work were applied with the same seismic class and earthquake load as the dam body according to the 『Dam seismic design (KDS 57 17 00: 2019)』. The seismic class and seismic performance of each dam are shown in Table 5.

Table 3 : Seismic Level for Dams

Seismic Level	Content	Return Period	
		FEE	NCE
Special Level	• Dam designated by client in terms of social, security and economics • Dams classified as multipurpose dams by law • Dam over 45m in height and total reservoir over 50 million m^3	200 year	2,400 year
Level 1	All dams except for Special level	100 year	1,000 year

Table 4 : Coeff. of Risk(I)

Return Period	50 yr	100 yr	200 yr	500 yr	1,000 yr	2,400 yr	4,800 yr
Coeff. of Risk(I)	0.4	0.57	0.73	1.0	1.4	2.0	2.6

Table 5 : Seismic level for targeted dam

Zone	Name	Completion year	Zone	Seismic Level	EPGA
Han-River Zone	Kawang-dong	1988	Zone I	Level 1	0.154g
	Dal-bang	1990	Zone I	Level 1	0.154g
Nakdong–River Zone	Young-cheon	1980	Zone I	Level 1	0.154g
	An-gye	1971	Zone I	Level 1	0.154g
	Gam-po	1996	Zone I	Level 1	0.154g
	Un-mun	2006	Zone I	Special level	0.220g
	Dae-gok	2005	Zone I	Level 1	0.154g
	Sa-yeon	1965	Zone I	Level 1	0.154g
	Da-am	1969	Zone I	Level 1	0.154g
	Sun-am	1964	Zone I	Level 1	0.154g
	Yeon-cho	1979	Zone I	Level 1	0.154g
Geum, Young, Seom Zone	Gu-cheon	1987	Zone I	Level 1	0.154g
	Su-eo	1978	Zone I	Level 1	0.154g
	Pyung-lim	2007	Zone I	Level 1	0.154g

6.2 The Result of seismic evaluation performance

As a result of the 1st seismic evaluation (brief analysis) for the 78EA including Kwang-dong dam, total 72 structures were satisfied with stability for seismic load. So, 6 structures un-satisfied and 5 tested as demonstration facilities in the 1st year were performed the 2nd detailed seismic evaluation. (Precision analysis)

The intake tower Br. of Gam-po dam, the spillway, intake tower Br. and the Diversion tunnel of the Sun-am dam were finally confirmed that it did not satisfy with seismic performance. And intake tower Br, of Su-eo dam is classified as a facility that does not have final seismic performance without precision analysis because it does not have a structural problem caused by external force such as seismic force, but a supporting length according to the specification of coping.

In conclusion, 5 facilities among the 78 ones were evaluated not to be satisfied the required capacity for seismic performance.

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Table 6 : Seismic evaluation performance status

Analysis Level	Nos. of places	The Result	
		Satisfied	Not Satisfied
The 1st analysis	78 EA	72 / 78	6 / 78
The 2nd analysis	11 EA	6 / 11	5 / 11

Table 7 : The 2nd seismic evaluation performance status

Name	Facility	Return Period	The 1st Analysis	The 2nd Analysis	NOTE
Young-cheon	Spillway	1,000 yr	O.K	O.K	Demonstration
	Intake Tower Br.	1,000 yr	O.K	O.K	Demonstration
	Diversion tunnel	1,000 yr	O.K	O.K	Demonstration
Gam-po	Intake Tower Br.	1,000 yr	N.G	N.G	
Un-mun	Diversion Tunnel	2,400 yr	N.G	O.K	
	Spillway br.	2,400 yr	O.K	O.K	Demonstration
	Gate	2,400 yr	O.K	O.K	Demonstration
Sun-am	Diversion Tunnel	1,000 yr	N.G	N.G	
	Intake Tower Br.	1,000 yr	N.G	N.G	
	Gate	1,000 yr	N.G	N.G	
Su-eo	Intake Tower Br.	1,000 yr	N.G	N.G	

Table 8 : Seismic evaluation performance status for facilities

Structure	Quantity of Target		The 1st Analysis		The 2nd Analysis		Verification of executed evaluation
	Seismic Evaluation	Verification	Satisfaction	Unsatisfiedness	Satisfaction	Unsatisfiedness	
Spillway	18	-	16	2	2	1	-
Intake tower	6	16	6	-	-	-	16
Intake tower Br.	10	-	7	3	1	3	-
Spillway Br.	9	-	9	-	1	-	-
Waterway tunnel	17	-	15	1	1	1	-
Power plant	5	-	5	-	-	-	-
Gate	7	-	7	-	1	-	-
Hoist	7	-	7	-	-	-	-
Total	78	16	72 / 78	6 / 78	6 / 11	5 / 11	16 / 16

7. SEISMIC PERFORMANCE IMPROVEMENT PLAN

7.1 Cause analysis and Performance improvement

78 EA are included in this task. And for the total five facilities that fail to finally secure seismic performance, the causes and repair and reinforcing methods are analyzed considering economic and construction efficiency. The results are summarized in Table 6.

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Table 9 : Cause analysis and performance improvement

Dam Name	**Subsidiary Facility**	**Cause analysis result**	**Performance improvement**
Gam-po Dam	Intake tower bridge	• At fixed abutment support, bearing capacity and anchor safety are not secured for the longitudinal force caused by couple force by lateral load.	◦Replace (steel) pot bearing with elastic bearing.
Seon-am Dam	Spillway	• At U-Type channel walls and floors, the safety is not secured due to lack of reinforcing bars.	◦Installation of upper slab to share load and rein forcement inside wall.
	Intake tower bridge	• The bridge is constructed of concrete without steel bar, so the seismic performance is not secured both at the foundation and at the bottom of the column. bridge fall is also possible.	◦Enlarge section in pier foundation and columns.
	Waterway tunnel	• In places with deep soil depth and poor ground conditions, the seismic performance is not secured for the bottom slab section.	◦Fill the part except steel pipe with concrete.
Su-eo Dam	Intake tower bridge	• Lack of minimum seating length determined by pier specification(length, height, etc,.)	◦Coping expansion (200mm or more)

Table 10 : Panorama of the auxiliary facilities of dam

Seon-am Dam Spillway

Seon-am Dam Waterway tunnel

7.2 Seismic performance improvement plan

For the facilities that do not secure seismic performance, repair and reinforcing method was selected and the cost was estimated. The priority was suggested considering the importance and urgency of the facilities, and distance from dam. The cost estimation was done by the lowest price based on the comprehensive「Price information 2019」and Public procurement service.

Table 11 : Seismic performance improvement plan

Dam Name	Subsidiary Facility	Repair and reinforcing method	Cost Estimation (1000 won)	Priority
Gam-po Dam	Intake tower bridge	Replacing support	62,862	2
Seon-am Dam	Spillway	Upper slab Installation Stiffener installation inside the wall	78,000	1
	Intake tower bridge	Section expansion in pier foundation and columns	198,000	1
	Waterway tunnel	Concrete filling	114,800	1
Su-eo Dam	Intake tower bridge	Coping expansion	111,622	2

7.3 Review the results

In preparation for frequent earthquakes, national attention has been focused. As a result, in January 2019, the seismic design standards for dams were strengthened, and a rational procedure was established by conducting a systematic seismic performance evaluation of aging dam attachment facilities in consideration of the strengthened standards.

Based on this data, reasonable seismic performance evaluation techniques are continuously improved, and it is necessary to prepare a framework for the long-term use of facilities safely through efficient evaluation and seismic performance improvement according to the result.