EARLY-ALERT SYSTEM OF RESERVOIR FAILURES USING GROUND WATER LEVEL

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Abstract - Climate change and facility aging lead to the reduction of reservoir safety that may bring reservoir failure, which results in the loss of lives and property damage in downstream areas. Therefore, it is necessary for downstream residents to provide an Early-Alert System for Reservoir (Dam) Failure to detect early signs of failure (with sensors) in real-time and perform safety management to prevent or minimize possible damage. Ground water level meters were installed to monitor changes of seepage line for understanding stability of dam body, and the management criteria were established. 15 analyzed data results showed that the values are scattered. It means that each reservoir has its own geotechnical characteristics, very different from others, so it is necessary to establish individual management criteria of ground water level based on 1 year test monitoring to set up for numerical fitting.

Keywords - Early Alert, Ground Water Level, Management Criteria, Reservoir Failure

I. INTRODUCTION

Over the past 100 years, rainfall intensity has decreased by 18%, while precipitation has increased by 17% [2]. The increase in hydrologic variables due to climate change along with the aging of reservoirs threatens the stability of reservoirs. According to the "Statistical Yearbook of Land and Water Development for Agriculture [6]", there are 17,313 reservoirs designated as agricultural irrigation facilities, and about 51% of them are over 70 years old. The large increase in hydrologic variables due to meteorological variability, climate change and the rapid progress of facility aging threatens the stability of reservoirs. The lack of flood control capacity due to the hydrologic variables which have increased from the stage of design and the loss of function due to aging are directly linked to reservoir overflows and structure failures & damage.

In addition, the increasing number of residents due to the development of downstream areas is directly related to massive casualties and property damages. Therefore, along with the existing safety evaluation, a failure alert system that detects and controls early signs of failure and damage in real time, considering various risk factors and uncertainties, is desperately needed. There are four monitoring systems currently operating in South Korea: the "USN(Ubiquitous Sensor Network) Reservoir Failure Forecasting and Warning System" which is an information pilot project of Korea Rural Community Corporation, the "Disaster Prevention Monitoring System" of Korea Rural Community Corporation, the "USN Steep Slope Failure Forecasting and Warning System" of the Ministry of Public Safety and Security, and the "Waterfront Structure Integrated Safety Management System" of Korea Water Resources Corporation (K-water) [3, 4]. These similar systems are established and used in consideration of various factors, but the management criteria are still needed to be improved. This study aims to verify the established ground water management criteria for early alert of reservoir failures through the analysis of the data of ground water level and rainfall in order to detect signs of losing stability of dam body and minimize consequences in the event of failure.

II. SAFETY MANAGEMENT OF RESERVOIR

According to the Rearrangement of Agricultural and Fishing Villages Act [5], domestic reservoirs are classified into Level 1 of 1,197 and Level 2 of 16,203, and subject to safety management according to the safety grade (Table 1) [1]. In the case of Level 1 reservoirs (reservoirs with a capacity of 300,000 tons or more), they are checked for safety inspection and precision safety diagnosis according to the system. However, Level 2 reservoirs (reservoirs with a capacity of 300,000 tons or less) can receive safety inspections only on a quarterly basis, and if there is a sign of abnormality, precision safety diagnosis can be requested.

Safety grade	Condition of Structures
A	Excellent condition of structure
B	Mostly excellent condition of structure
C	Normal condition without difficulties in the safety management
D	Condition requiring partial repair and reinforcement
E	Condition requiring urgent repair and reinforcement

Table 1 Classification of state evaluation of structures

Among domestic reservoirs, the reservoirs which are actually susceptible to failure, are small and medium reservoirs with reservoir capacity between 200,000 and 300,000 tons. There are 884 such reservoirs scattered throughout the country. It also shows that the safety grade does not guarantee the actual safety of reservoir.

In this reality, the configuration of the failure alert system should be constructed and operated for small and medium reservoirs, which are vulnerable due to poor management, by counteracting the aging of facilities, the rapid increase in hydrologic variables due to climate change, and the increasing number of residents due to the development of reservoir downstream areas, in order to minimize damage on humans and properties.

III. GROUND WATER LEVEL MANAGEMENT CRITERIA

With regard to the dam body failure by losing stability of dam body, which is one of the major destruction scenarios of the domestic reservoir (fill dam), the measurements of the reservoir (fill dam) change ratio of ground water level up to normal seepage per day can be used directly as criteria for judging the risk of the reservoir.

Phase	Caution	Alert	Danger	
Bundang Line Subway the 4th Site	Over 1m/week			
Suwon ~ Incheon Subway the 1st Site	H≤0.1m	0.1m≤H≤ 0.3m	H ≥ 0.3m	H = Change of Water Level/day
Facilities at Airport	H≤0.5m	0.5m≤H≤ 1.0m	H ≥ 1.0m	

Table 2. Early Warning Criteria of Ground Water Level Meter at Earth Retaining Wall

The ground water level has a great influence on the stability of the structure of the cut slope, the fill slope, and the earth retaining wall. When stability analysis is performed, compared with the safety factor of a dry slope with no ground water level, its safety factor may be reduced to about 50% due to the increase of water pressure when the ground water level reaches the ground level. Therefore, the ground water level changes of structures like reservoirs can be used as management criteria to detect the signs of reservoir failure. The early warning criteria of the ground water level meter are also used as a method to detect risk in advance by monitoring the variation of the ground water level of the temporary earth retaining wall (Table 2). Through the result analysis of the ground water level management criteria, it is considered as a very dangerous stage when the daily water level changes by more than 15% of the height of the reservoir.

Phase	Criteria
Attention (Blue)	Change of Ground Water Level(H/day) exceeds normal seepage inland
Caution (Yellow)	Change of Ground Water Level(H/day) exceeds 5% of Dam Height inland
Alert (Orange)	Change of Ground Water Level(H/day) exceeds 10% of Dam Height inland
Serious (Red)	Change of Ground Water Level(H/day) exceeds 15% of Dam Height inland

Table 3. Alert management criteria of ground water level [4]

Therefore, it is set as the management criteria of the serious phase. The water level change criteria were decreased step by step and set as the early warning criteria for the ground water level (Table 3). The management criteria based on the reservoir ground water level are as follows. The attention phase is set considering that the reservoir ground water level exceeds the normal seepage line inland. The caution phase is set based on the moment when the ground water level exceeds 5% of dam height inland per day. The alert phase is based on the point when the ground water level exceeds 10% of dam height inland per day. It is considered as the serious phase, when the reservoir ground water level exceeds 15% of dam height inland per day and the risk of dam failure is greatly increased by exceeding the reservoir limit.

IV. METHOD AND ANALYSIS FOR VERIFICATION

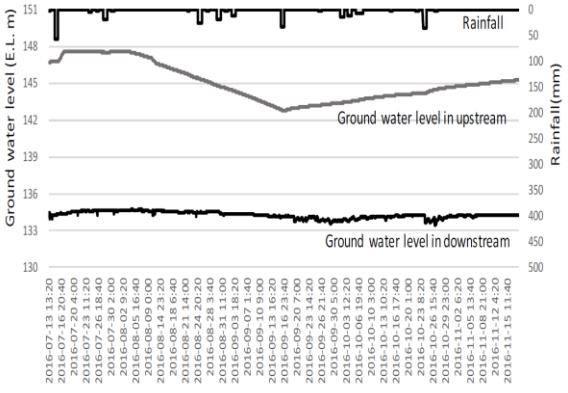


Figure 1. Rainfall and Ground Water Level Data of Gungchon Reservoir

Fifteen reservoirs were selected from the reservoirs with a dam height of 10m or more in consideration of

location, type, and water storage capacity. Long-term measurement is required to find and analyze a trend. Among the collected data, 2016 data was mainly analyzed. In order to analyze the correlation between the early warning criteria and the ground water level management criteria, the daily change rate of the ground water level relative to dam height was derived after applying an weighting factor and the correlation with the management criteria was analyzed. The actual rainfall was compared with the average rainfall. The heavy rainfall weighting factor was used as the weighting factor since it had bigger value when comparing the rainfall weighting factor in a normal year and the heavy rainfall weighting factor 43% (based on 18% decrease in rainfall days and 17% increase in rainfall over the last 100 years) [2]. In the case of Gungchon reservoir, as shown in Figure 1, the upstream ground water level moved with a certain influence of rainfall during the analysis period, but the downstream ground water level was not affected by the rainfall and didn't not change much.

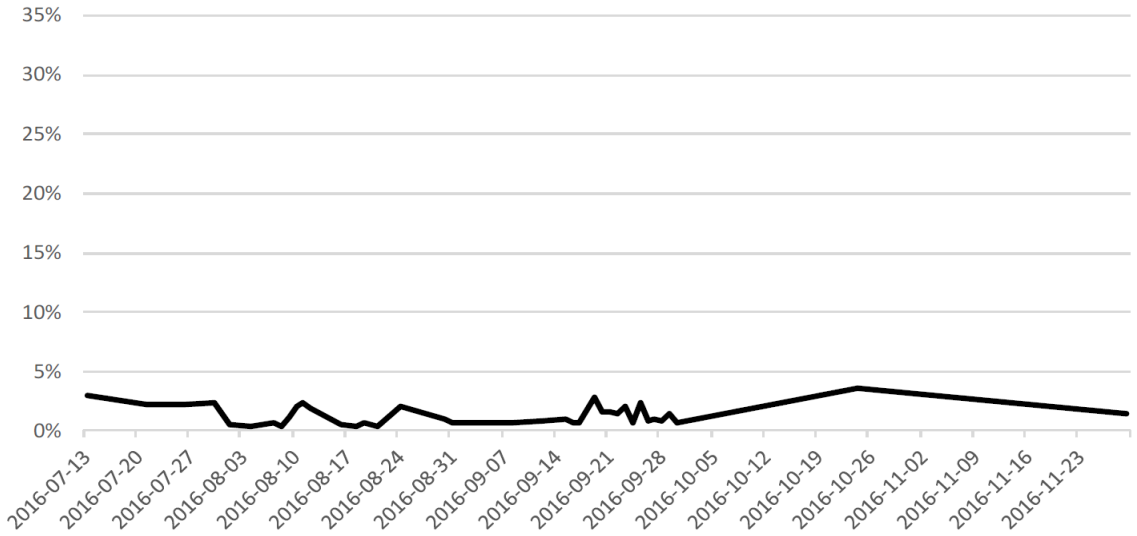


Figure 2. Daily Change Rate of Downstream Ground Water Level of Gungchon Reservoir

Considering that the individual risk management criteria of ground water level is the daily change in water level relative to reservoir height, the daily change rate of the downstream ground water level of Gungchon reservoir was analyzed. As a result, the daily change rate of the downstream ground water varies from a minimum of 0.08% to a maximum of 3.59% over the period (Figure 2). It shows that the values between August and September soar when applying the heavy rainfall weighting factor to the daily change rate of the downstream ground water level of Gungchon reservoir than when applying the average rainfall weighting factor. In other words, all the points up to the Caution phase and the Alert phase in the analysis applied with the average rainfall factor rose above the Serious phase with the heavy rainfall factor.

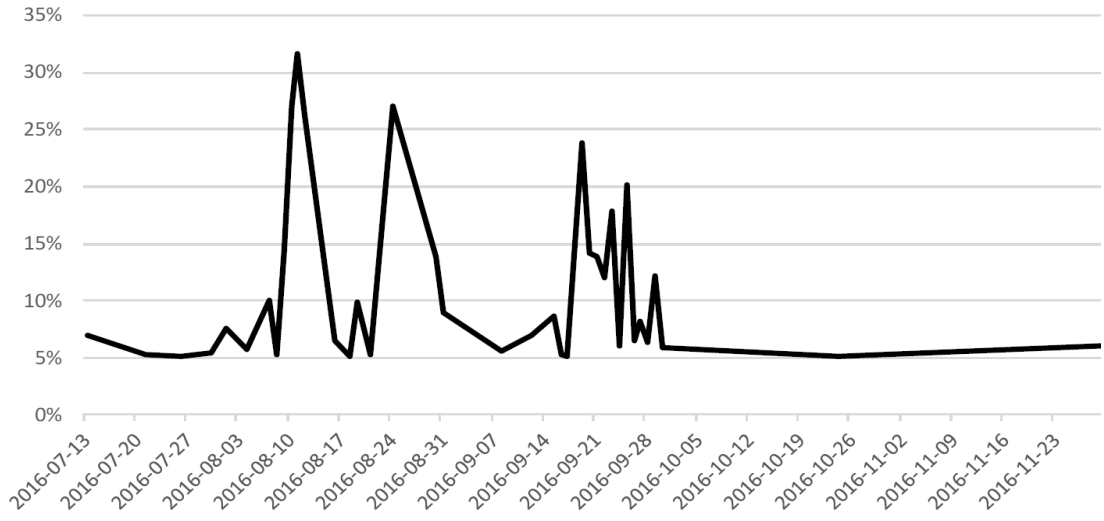


Figure 3. Daily Change Rate of the Downstream Ground Water Level of Gungchon Reservoir after applying the Heavy Rainfall

Weighting Factor

Assuming that Gungchon reservoir has more than average rainfall or heavy rainfall as a weighting factor, it can be seen that the existing management criteria are set too low (Figure 3). When the heavy rainfall weighting factor was applied to the daily change rate of the downstream groundwater level over the analysis period, in general the change rate increased significantly. Assuming that the reservoir faces a heavy rainfall event, there will be quite a few days in January, May-June, and August-September, with daily change rate of more than 5%, which is the lowest level of the management criteria. Therefore, it is not appropriate to set the management criteria to 5%~10%, 10%~15%, and 15% for the reservoir. It is necessary to conduct further data analysis in order to raise the criteria and review the risk of levee piping.

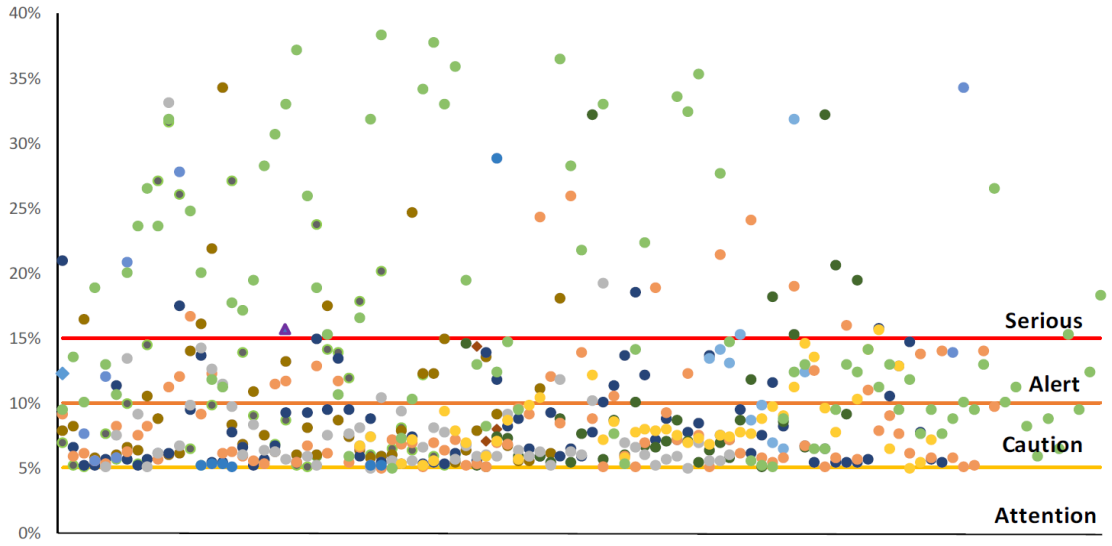


Figure 4. Distribution of Daily Change Rate of the Ground Water Level of 15 Reservoirs after applying the Heavy Rain Weighting Factor

	Target Reservoir	MAX Value	Caution Phase (FREQ)	Alert Phase (FREQ)	Serious Phase (FREQ)
1	Geodong	12.25%	1	1	-
2	Wolsong	3.21%	-	-	-
3	Gosu	-	-	-	-
4	Gungchon	31.65%	38	13	7
5	Hwajug	15.74%	1	1	1
6	Seogdong	5.89%	1	-	-
7	Hwagjang	2.81%	-	-	-
8	Songgang	-	-	-	-
9	Hwanglag	14.36%	4	1	-
10	Eoeun	4.30%	-	-	-
11	Singeum	43.92%	48	17	8
12	Chodae	42.80%	44	13	3
13	Sowol	48.67%	29	9	7
14	Jeomgok	31.85%	10	6	2
15	Haksapyeong	25.92%	49	15	6

Table 4. Analysis Table of the Correlation between the Daily Ground Water Level Change Rate applied with the Heavy Rainfall

Weighting Factor by Reservoir and the Management Criteria

The correlation with the values of the daily change rate of the downstream ground water level of 15 target reservoirs was analyzed after applying the heavy rainfall weighting factor. The distribution in Figure 4 is summarized in correlation with the ground water management criteria in Table 4. As a result of analyzing the daily change rate of the ground water level of 15 reservoirs and the correlation with each phase, it can be seen that the distribution of daily change rate, which is the criteria for each phase, varies by reservoir without showing a certain pattern. Thus, the existing management criteria, that divide the Caution, Alert, and Serious phases into 5%, 10%, and 15% daily change rate, are considered as rough criteria to apply collectively to all reservoirs with different sensitivity. Therefore, it is reasonable that the existing criteria should be used as initial values before setting criteria applicable to each reservoir, and in the meantime, groundwater level monitoring should be performed for one year by reservoir so that the phase values can be modified to fit for each reservoir by calculating the daily change rate.

V. CONCLUSION

In this study, the daily change rate of the ground water level of 15 reservoirs and the correlation with each phase was compared and analyzed.

1) The established management criteria, which divide the daily change rate of the ground water level into 5%, 10%, and 15%, are appropriate as initial values for applying collectively to all reservoirs with different sensitivity.
2) Each reservoir has its own unique characteristics and environment such as dam body construction method, dam height, and reservoir size. Therefore, it is reasonable to adjust the phase values by appropriately calculating daily change rate during the 1 year preliminary period for the establishment of criteria applicable to each reservoir.

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