*ICOLD Symposium on Sustainable Development of Dams and River Basins, 24th - 27th February, 2021, New Delhi*

# CALCULATION OF MANAGEMENT CRITERIA VALUES FOR LEAKAGE QUANTITY IN CONCRETE DAM

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## ABSTRACT

*Methods for calculating instrumentation management criteria values in dam include the application of the design basis values (permissible values), the statistical analysis using accumulated measurement data, and the calculation of the control values using empirical formulas.*

*In this study, a statistical analysis using accumulated measurement data is intended to calculate the management criteria values for water leakage quantity in concrete dams, and the range of the control values was calculated based on the lower and upper limits of the scaled data.Typically, the confidence intervals used for statistical analysis use 95% and 99% confidence in the mean values, which are applied to the calculation of the control criteria. Quantitative management is possible with the calculated control values, and the control values shall be managed by calculating the new control criteria using newly scaled measurement data at every stated period after the initial calculation.*

## 1. GENERAL INSTRUCTIONS

• Calculation of the Management Standard Values for Water Leakage Quantity in Concrete Dam

The calculation of the water leakage control value of the concrete dam was based on the lower limit and upper limit of the accumulated data, as was the case with the "Improvement of Dam Measuring System" performed in 2013.

- When calculating the water leakage management criteria, the management criteria for the leakage quantity was analyzed at a 95% confidence level and calculated using 1.96 times the standard deviation from the average of the instrumentation data accumulated. For the lower limit, the minimum value of the measured data is set if the control base for leakage containing negative values is calculated when the margin of 95% confidence interval is used depending on the measurement data.
- The instrumentation management criteria values of water leakage quantity of concrete dam

| Classification | | The formula | Criteria |
|---|---|---|---|
| **Concrete Dam** | H Dam | lower limit : 38.07 - (1.96×16.49) = 5.75ℓ/min<br>upper limit : 38.07 + (1.96×16.49) = 70.39ℓ/min | 5 ~ 71ℓ/min |
| | P Dam | lower limit : 46.21 - (1.96×15) = 16.81ℓ/min<br>upper limit : 46.21 + (1.96×15) = 75.62ℓ/min | 16 ~ 76ℓ/min |
| | Y Dam | lower limit: 29.42 - (1.96×13.01) = 3.92ℓ/min<br>upper limit: 29.42 + (1.96×13.01) = 54.91ℓ/min | 3 ~ 55ℓ/min |

* The formula for calculating the instrumentation management criteria values of water leakage quantity

* The instrumentation management criteria

## 2. ANALYSIS RESULTS

### 2.1 Methods for Calculating Instrumentation Management Criteria Values in Dam

Methods for calculating instrumentation management criteria values in dam include the application of the design basis values (permissible values), the statistical analysis using accumulated measurement data, and the calculation of the control values using empirical formulas.

In this study, the management criteria values were calculated through statistical analysis using measurement data accumulated in each dam.

(1) Statistical Analysis Using Accumulated Measurement Data

If measurement data have been accumulated since completion of the dam, the overall behavior of the dam can be determined from the completion to the present, and a statistical analysis can be used to calculate reasonable control criteria.

In addition, statistical analysis of the data has the advantage of considering the error factors included in the measurement data. If the data accumulated is significantly affected by external factors, it can be classified as an outlier in the statistical sense and the data can be excluded, thus providing reasonable control criteria.

Generally, the confidence intervals used in statistical analyses use 95% and 99% confidence in the mean values, which could be applied to the calculation of the control criteria.

the calculation of a reference range with 95% confidence

the calculation of a reference range with 99% confidence

$\overline{X}$ = sample mean, *SE* = standard error

## 2.2 Calculation of the Management Criteria Values Using Empirical Formulas

(1) Data Collection and Screening for Calculating Management Criteria

Based on the data used to calculate the management standard in the "Detail Design for Improvement of Dam Instrumentation System" performed in 2013, the data accumulated until recently were collected and recalculated.

Accumulated measurement data include outliers due to malfunctions caused by external environment such as instrumentation error -sensor sensitivity degradation, noise generation, sensor failure, errors due to inspection and replacement- and rainfall at sensor parts. Since the outlier has an adverse effect on the statistical analysis, the problem is that the control criteria are excessively high or low, a data screening process that excludes the outlier is needed to determine the reliable control criteria.

Outlier is a material that is significantly different from the trend of the overall data, and if determined with these outliers, the results of the calculation of the control base will vary considerably. Many theories exist for determining outlier, and in this study, the quadrant method, one of the widely used methods of interval setting, was used.

Quadrant methods should first calculate the Quartile. Quartile is the data that lists the data in order of size and corresponds to the point where the cumulative percentage is quadrated. The first quartile is a value in a 25% position when the entire data is listed in order, and the third quartile in a 75% position.

To calculate the lower and upper limits for outlier, use the following formula

- the lower limit : the first quartile – 1.5 (the 3rd quartile – the1st quartile)
- the upper limit : the third quartile + 1.5 (the 3rd quartile – the1st quartile)

Therefore, the criteria of the data that are used to calculate the control criteria or are classified as outlier and excluded are as follows.

Nomal Data : the lower limit < data < the upper limit

Outlier : data < the lower limit, data > the upper limit

The sequence for calculating the effective data range and excluding the outlier is as follows.

① Sort data in order from small to large.

② Calculate the median, the first quartile, and the third quartile of the data.

③ Calculate IQR (the Interquartile Range) using the first and third quartiles.
→ (IQR = 3rd quartile – 1st quartile)

④ 1.5×IQR

⑤ Calculate the upper limit of the effective data by adding the 1.5×IQR value to the third quartile.

⑥ Calculate the lower limit of the effective data by subtracting the 1.5×IQR value from the first quartile.

⑦ Calculate the range of the effective data.
→ (1st quartile-1.5×IQR) ≤ effective data ≤ (3rd quartile + 1.5×IQR)

⑧ Exclude the values out of the effective data from the date.

(2) Calculating Management Criteria

In the "Detail Design for Implementation of Dam Instrumentation System" conducted in 2013, statistics were applied to calculate the control criteria to extract samples from the population, and parameters (population mean, population standard deviation) were estimated from the statistics of the extracted samples (sample mean, sample standard deviation).

Interval estimates were used to estimate probabilistically the interval in which the population mean would exist, and the typical interval estimation, Confidence interval, was used.

Confidence intervals which are areas where actual parameters are expected to exist allow interval estimation of different levels including 90%, 95% and 99% confidence intervals, and the 95% confidence interval was applied in the " Detail Design for Implementation of Dam Instrumentation System." 95% confidence intervals are expressed in the form of the beginning of the section and the end of the section, which is reliable that there is a 95% probability that there is an actual population mean within the predicted interval.

To calculate the control criteria using 95% confidence intervals from accumulated instrumentation data, use 1.96 times the standard deviation if the sample number is sufficient; $n \geq 30$. If the number of samples is small; $n \leq 30$, the standard deviation is multiplied by 2,776.

Average value of the instrument ± (Standard deviation or Maximum deviation) ×1.96 ($n \geq 30$)

Average value of the instrument ± (Standard deviation or Maximum deviation) ×2.776 ($n \leq 30$)

The "Detail Design for Implementation of Dam Instrumentation System" used 1.96 times the maximum deviation or standard deviation from the mean value of the accumulated instrumentation data to calculate instrumentation management criteria values in dam

In this study, the instrumentation data accumulated until recently used the calculation formula above to recalculate the management criteria values for water leakage quantity.

Calculation of the management criteria values for water leakage quantity for H-dams is as follows.

(1) Leakage System

**Table** : Minimum and maximum values in raw data

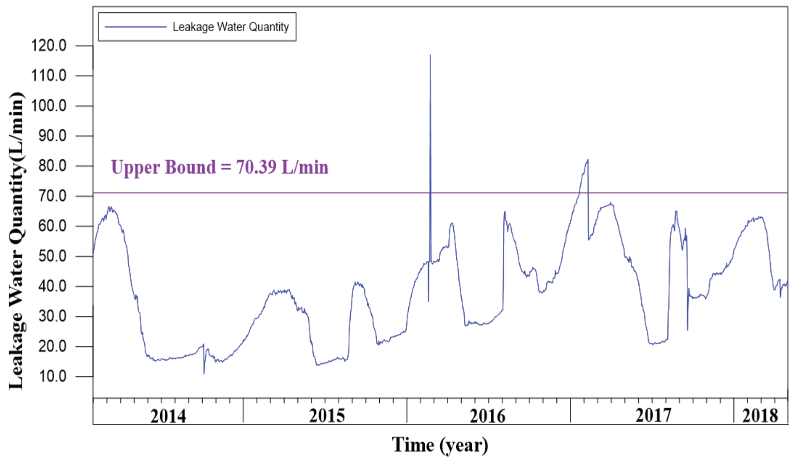
| Minimum | Maximum |
|---|---|
| 10.92ℓ/min | 116.96ℓ/min |

**Table** : Calculation of the management criteria values for water leakage quantity

| Minimum | Maximum | Average | Standard deviation |
|---|---|---|---|
| 10.92ℓ/min | 82.36ℓ/min | 38.07ℓ/min | 16.49ℓ/min |
| 95% the min of confidence interval | | 38.07 - (1.96×16.49) = 5.75ℓ/min | |
| 95% the max of confidence interval | | 38.07 + (1.96×16.49) = 70.39ℓ/min | |
| the management criteria | | 5 ~ 71ℓ/min | |

*Duration of data used to calculate the management criteria: 01/01/14~03/31/18

*The data that had excluded outliers were used for calculating maximum, minimum, average, standard deviation, and the management criteria.




*Data used to draw the elapsed time change graphs are raw data that do not exclude outliers.

**Figure 1** : H-Dam Leakage Graph

P-Dam

Calculation of the management criteria values for water leakage quantity for P-dams is as follows.

**Table** : Minimum and maximum values in raw data

| Minimum | Maximum |
|---|---|
| 15.95ℓ/min | 82.17ℓ/min |

**Table** : Calculation of the management criteria values for water leakage quantity

| **Minimum** | **Maximum** | **Average** | **Standard deviation** |
|---|---|---|---|
| 15.95ℓ/min | 82.17ℓ/min | 46.21ℓ/min | 15ℓ/min |
| 95% the min of confidence interval | | 46.21 - (1.96×15) = 16.81ℓ/min | |
| 95% the max of confidence interval | | 46.21 + (1.96×15) = 75.62ℓ/min | |
| the management criteria | | 16ℓ/min ~ 76ℓ/min | |

*Duration of data used to calculate the management criteria: 01/01/14~03/31/18

*The data that had excluded outliers were used for calculating maximum, minimum, average, standard deviation, and the management criteria.

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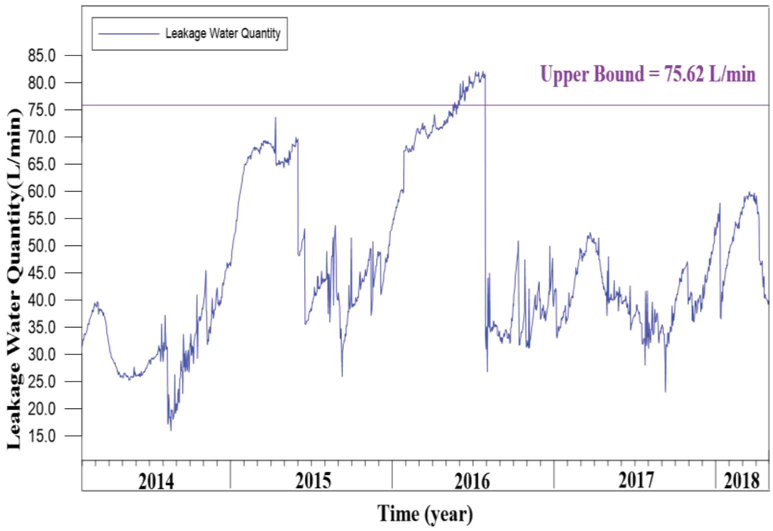



**Figure 2** : P-Dam Leakage Graph

Y-Dam

Calculation of the management criteria values for water leakage quantity for Y-dams is as follows.

**Table** : Minimum and maximum values in raw data

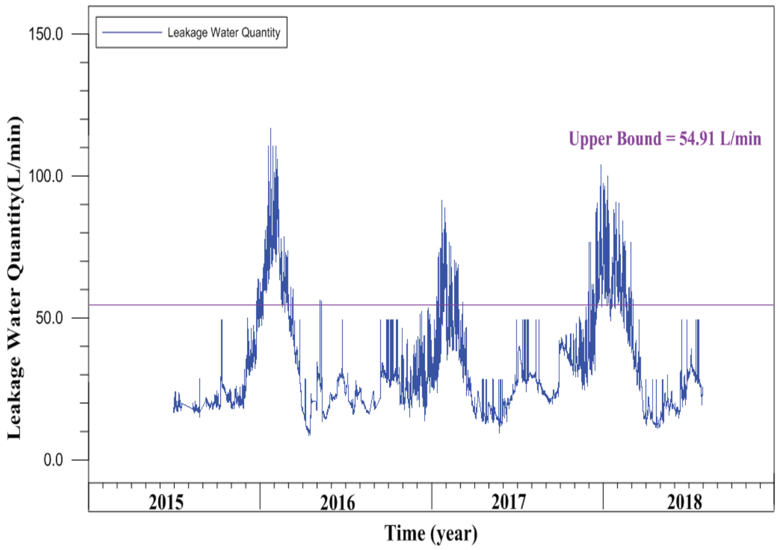
| **Minimum** | **Maximum** |
|---|---|
| 8.28ℓ/min | 116.73ℓ/min |

**Table** : Calculation of the management criteria values for water leakage quantity

| **Minimum** | **Maximum** | **Average** | **Standard deviation** |
|---|---|---|---|
| 8.28ℓ/min | 67.56ℓ/min | 29.42ℓ/min | 13.01ℓ/min |
| 95% the min of confidence interval | | 29.42 - (1.96×13.01) = 3.92ℓ/min | |
| 95% the max of confidence interval | | 29.42 + (1.96×13.01) = 54.91ℓ/min | |
| the management criteria | | 3ℓ/min ~ 55ℓ/min | |

*Duration of data used to calculate the management criteria: 01/01/14~03/31/18

*The data that had excluded outliers were used for calculating maximum, minimum, average, standard deviation, and the management criteria.




*Data used to draw the elapsed time change graphs are raw data that do not exclude outliers.

**Figure 3** : Y-Dam Leakage Graph

## 3. CONCLUSION

Through statistical analysis using the accumulated instrumentation data of concrete dams, the water leakage management criteria were calculated. The calculated management criteria can be utilized for quantitative management of dam water leakage, and the new control criteria can be calculated using newly scaled measurement data every certain period after the initial calculation to improve reliability. In addition, the system needs to be improved so that the data on rainfall for linkage analysis with the leakage quantity in concrete dam can be linked to the data of the Korea Meteorological Administration.

## REFERENCES

The design standard on dams. *Korea Water Resources Association*

Engineering guidelines. FERC, 1991.

The detailed guideline of the safety inspection and in-depth inspection on dams (In Korean). KISTEC, 2010.