# A MEASURE OF DAM SAFETY OF EXISTING MULTI-PURPOSE DAM IN KOREA

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## ABSTRACT

*According to increasing rainfall caused by climate change, including global warming and abnormal weather, flood safety of existing dams is greatly threatened. As a result, South Korea's 20 multi-purpose dams have been taking steps to increase their design flood volume since 2004 to ensure safety of dams caused by floods. A most structural measures include establishing emergency or auxiliary spillway to safely discharge the increase in the design flood downstream to ensure the safety of the dam. The Nam River Dam is operated by distributing and discharging into other stream using the tailrace as well as the Nam River during the flood. And compared to other dams, it has a very small flood control capacity compared to the basin area. Therefore, I would like to introduce to Nam River Dam, which is currently the only multi-purpose dam in Korea to enhance its safety.*

## 1. INTRODUCTION

### 1.1 Necessity of business

The damage from the design flood is also expected to increase in the future given that recent climate change caused by global warming is taking place worldwide, and that South Korea has caused massive flood damage due to torrential rains across the country-wide. The increased casualties and property damage cannot be compared to the actual dam collapse in the event of a flood.

The Nam River basin has been prone to heavy rains due to climate change, and the possibility of flooding has increased due to the change in the hydrological environment due to increased rainfall, and the hydrological safety of the Nam River Dam is also needed. Flood damage in the Nam River Dam basin is caused by repeated large-scale flood damage caused by typhoons Rusa (‘02), Maemi (‘03), Ewiniar (‘06), Muifa (‘11) and Sanba (‘12), which is caused by high flood rates due to the geographical features of the Nam River basin and low-lying areas.

Moreover, since the quantity of the Nam River Dam is relatively small compared to the quantity introduced, the level of the reservoir should be kept below a certain level to ensure flood control capability. In fact, there have been five times since the reinforcement of the Nam River Dam in 1999 that threaten the safety of the dam by exceeding the amount of design flood, and preliminary discharges of water in each category of precipitation are flexible, but fundamental measures are urgently needed.

### 1.2 Current status of Multi-purpose Dams flood control enhancement in Korea

To date, 18 dams have been completed for the flood control enhancement, 1 dam is under construction, and 1 dam(Nam River Dam) has not been started. Examples of these dams are summarized in the following Table 1.

## 2. NAM RIVER DAM

### 2.1 Overview of Nam River Dam

The existing Nam River Dam was reviewed as part of the Nakdong River Reconstruction Plan in 1920 and started construction in 1936. However, construction was stopped in 1969 due to the Second World War and the Korean War.

**Table 1** : Current Status of Dam Safety Projects for Existing Multi-purpose Dams in Korea

| Name of Dam | Completion year | Measures* | Name of Dam | Completion year | Measures* |
|---|---|---|---|---|---|
| Soyang River | 1973 | B | Boryeong | 2000 | C |
| Chungju | 1986 | B | Milyang | 2002 | C |
| Hapcheon | 1989 | E | Nam River | 2003 | B+D(Planning) |
| Buan | 1996 | C | Hoengseong | 2002 | F |
| Imha | 1993 | B | Janghung | 2007 | F |
| Daecheong | 1981 | B | Yongdam | 2006 | F |
| Andong | 1977 | B | Youngju | 2019 | F |
| Seomjin River | 1965 | B | Kimcheon-Buhang | 2016 | F |
| Juam (main) | 1992 | B | Sungduk | 2015 | F |
| Juam (balancing reservoir) | 1992 | A + C | Bohyeonsan | 2015 | F |
| | | | Gunwi | 2016 | F |

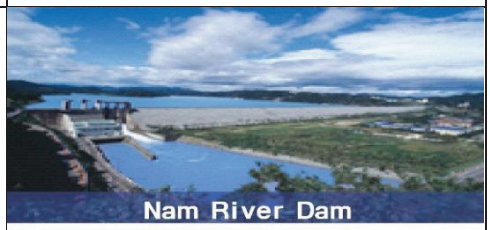
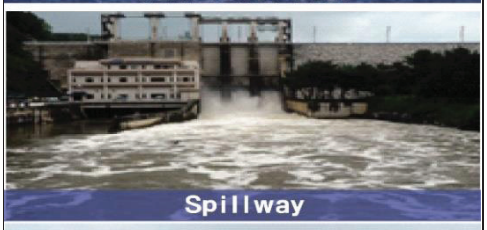
*A : improve the existing spillway B : build the auxiliary spillway C : expansion of parapet wall,

D : expansion of the regulating gate E : non-structural measure F : ensure safety

Since then, by the end of the 1980s, various demands for water increased due to the increase of land use and urban concentration of the population. Also, due to the frequent flooding, the necessity of the improvement of the flood control function also appeared in the safety of the existing Nam River Dam. Therefore, it is decided that the current Nam River Dam will be newly built at the downstream point of the old dam by supplementing the existing Nam River Dam to control flooding and water supply capacity.

The type of Nam River Dam is C.F.R.D. The main facility is 34m high and 1,126m long. It consists of a three-door spillway and a hydropower plant with a capacity of 14,000 kW. There is another C.G.D, 31m high and 246m long(Regulating gate), to discharge the flood to the Sacheon Bay.

**Table 2** : Nam River Dam Facility Specification

| Item | Specification | Foreground |
|---|---|---|
| 1. Hydrology | |  Nam River Dam |
| -P.M.F. | 15,800㎥/s | |
| -M.W.L | 49.3 EL.m | |
| 2. Reservior | | |
| -F.W.L. | 46 EL.m | |
| -N.H.W.L. | 41 EL.m | |
| -L.W.L. | 32 EL.m | |
| -Total Storage | 309.2*10$^6$㎥ |  Spillway |
| 3. Dam | | |
| -Type | CFRD | |
| -Crest Elevation | 51 m | |
| -Height | 34 m | |
| -Length | 1,126 m | |
| 4. Spillway | |  Regulating gate |
| -Type | Orifice 3gate | |
| -Outflow: 200yr (P.M.F.) | 800㎥/s(1,000㎥/s) | |
| 5. Regulation gate | | |
| -Type | Overflow 4gate +Orifice 8gate | |
| -Outflow: 200yr (P.M.F.) | 3,250㎥/s(6,000㎥/s) | |

## 2.2 Current Flood Control

The Nam River Dam operates a spillway in the main direction of the Nam River and an artificial waterway(Gahwa stream) in the direction of Sacheon Bay to control the planned flood volume.

At the time of completion of the planned flood in 1969, it was planned to discharge 2,000m$^3$/s from the spillway and 5,460m$^3$/s from the artificial waterway(Gahwa stream). However, flooding in the Jinju-city region occurred at the main head of the Nam River, and flooding of coastal farmland was caused by rising water levels in Sacheon Bay. Therefore, in 1999, when the planned flood flowed in at 10,400m$^3$/s through the reinforcement of the dam. It was changed to discharge

800m³/s from the spillway in the main direction of Nam River, 3,250m³/s from the artificial waterway and 6,350m³/s is stored in a reservoir.

The flood control method of the Nam River Dam is currently limited to 7,000m3/s(Nam River 1,000m³/s, Gahwa stream 6,000m³/s), if the discharge amount is maximized at the beginning of the flood to 4,050m³/s(Nam River 800m³/s, Gahwa stream 3,250m³/s) to reduce the reservoir water level sufficiently and increase the reservoir water level by exceeding the discharge amount to an EL.46.0m. The basic directions of flood control in the Nam River Dam are shown in Figure 1.

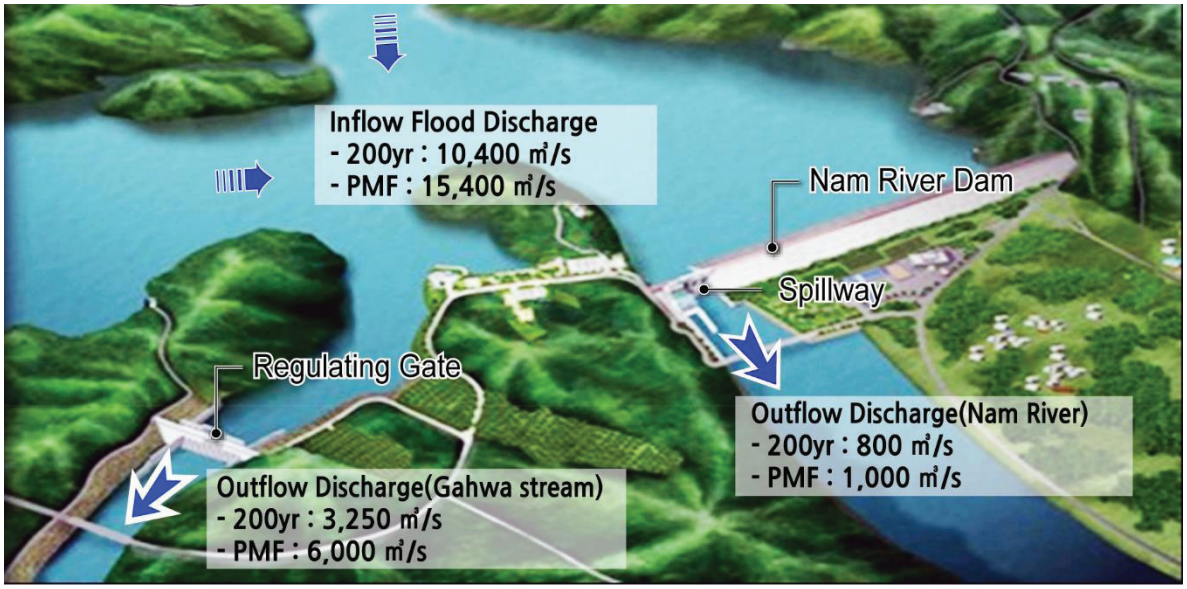


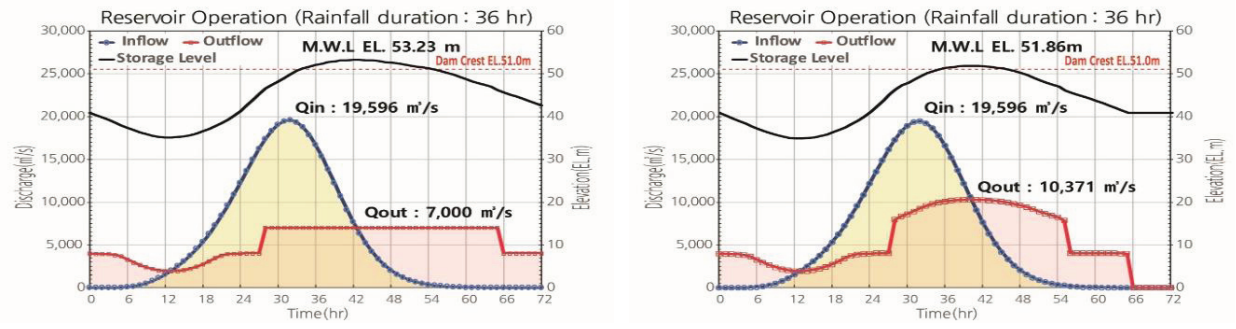

**Figure 1** : Flood control of the Nam River Dam(1999)

## 2.3 Problems

Although the Nam River Dam(with a basin area of (2,285km²) is the only multi-purpose dam that can control flooding in the watershed, compared to the Soyang River Dam(with a basin area of 2,703km²) , the reservoir capacity is about 10% and the flood control capacity is about 35%, making it very vulnerable to abnormal flooding among the Korea's dams.

Currently, the Nam River Dam uses flood control method to maximize flood control capacity through preliminary discharge to maximize flood control during the flood season due to its size and characteristics of the Nam River Basin. As it occurs, it is difficult to predict hydrology and it is expected to increase the difficulty of reservoir operation due to the limitation of Nam River Dam's ability to cope with flooding. In fact, after the Nam River Dam reinforcement in 1999, there have been five cases of threatening the safety of the dam exceeding the design flood (10,400m³/s).

When the P.M.F.(20,269m³/s) inflows from the existing Nam River Dam, in case of constant discharge of 1,000m³/s into Nam River and 6,000m³/s into Gahwa Stream, the current level exceeds the dam crest elevation (EL.51.0m) above 2.23m, and is now discharged. In case of maximum discharge of the existing facility, the maximum water level exceeds 0.86m. Therefore, the Nam River Dam is impossible to secure dam safety because the water level of the dam overtakes the crest of the dam. Figure 2.




Rigid ROM Full Open

**Figure 2** : Evaluation on a flood routing of the Nam River Dam.

## 3. NPLANNING OF FLOOD CONTROL FOR DAM SAFETY

### 3.1 Concept of hydrological safety

In order to perform more precise hydrological safety assessments for existing dams, the maximum capacity of the dam, including P.M.F.(probable maximum flood), discharge capacity, the maximum level of design flood inflow, and the clearance and acceptable reservoir level careful review is needed.

Hydrological safety review of the Nam River Dam examines the reservoir capacity curve, discharge capacity of existing spillway and regulating gate, calculates the maximum water level of Nam River Dam when P.M.F. inflows through a reservoir routing and compares the allowable maximum water level. This study analyzed the necessity of an enforced of flood control. The procedure for reviewing hydrological safety of Nam River Dam is as follows.

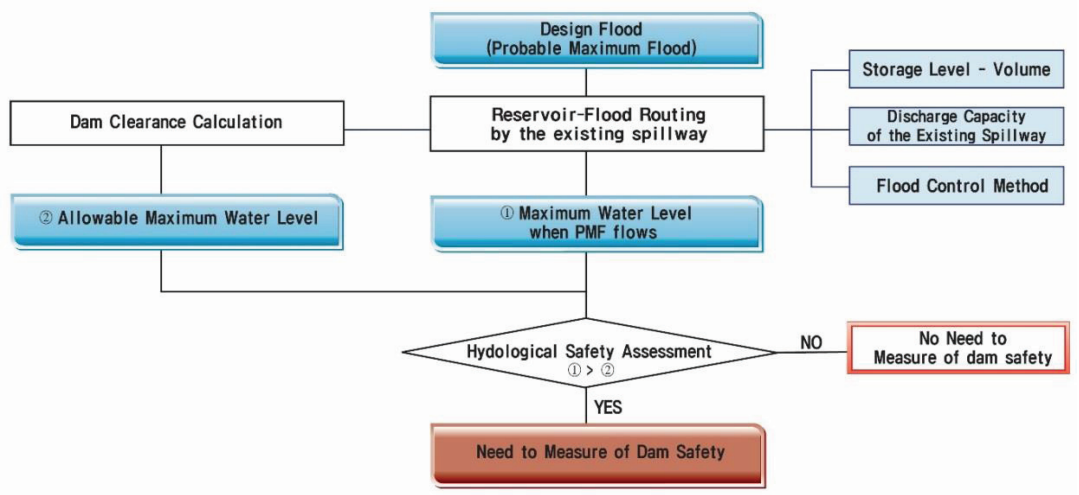



**Figure 3** : Process for Hydrological Safety Assessment

Since the construction of the Nam River Dam, hydrological conditions in Korea have changed drastically, including abnormal floods caused by extreme weather. The probable maximum flood was 15,800$m^3$/s at the time of construction, but according to this analysis, it is increased to 20,269$m^3$/s by about 28.3%, making it impossible to secure hydrological safety of the Nam River Dam. Therefore, the P.M.F. was evaluated for its flood control capacity and hydrological safety in the current facilities size and operation plan of Nam River Dam.

### 3.2 Distribution of the increment PMF

The Nam River Dam was connected to the current Gahwa stream by constructing an artificial waterway for flood protection of the Nam River and Nakdong rivers. The Nam River Dam currently lacks the flood control capacity compared to the basin area, and the preliminary discharge is initiated by opening the spillway and regulation gate based on the time of flooding in the basin.

As a result, unlike other dams, the discharges of floods are discharged to the main stream of Nam River and Gahwa stream, respectively, resulting in conflict due to differences in regional interests.

For the facility planning needed for an enforced of capacity in dam's flood control, the discharge operation plan was reviewed to minimize the conflicts between the neighboring regions of the dam, referring to the dam height increase plan and the downstream discharge plan. For this purpose, hydrological safety was analyzed by applying the current P.M.F. allocation and discharge rate to the dam height increase plan and the distribution and discharge method of Nam River and Gahwa stream.

- Case 1 : Dam height increase

  In order to respond to the Nam River Dam's P.M.F., the current flood control method is applied when the reservoir water level is below the design flood level EL.46.0m. If the water level exceeds the design flood level, this method was changed and reviewed, from the existing 7,000$m^3$/s limited discharge to full. This is to maximize the discharge capacity of existing spillway and Regulating Gate installed at Nam River Dam, and to increase surcharge storage for increased P.M.F. response without planning additional discharge facilities.

- Case 2 : Gahwa stream Discharge increase(Add a gates in the existing Regulating Gate)

  As an alternative to the additional discharge towards Gahwa stream, it can be divided into the method of establishing an auxiliary channel to increase the discharge capacity of the Nam River Dam and the expansion of the water gate on the left side of the existing Regulating Gate

- Case 3 : Nam River stream Discharge increase(Auxiliary spillway)

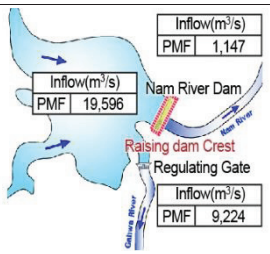
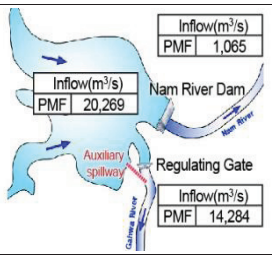
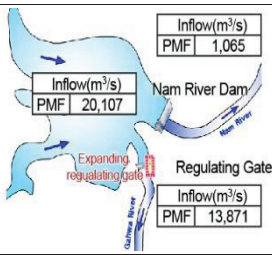
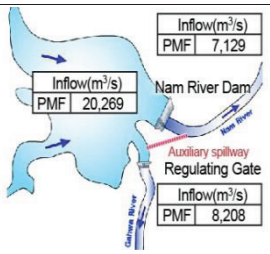
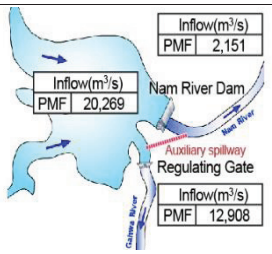
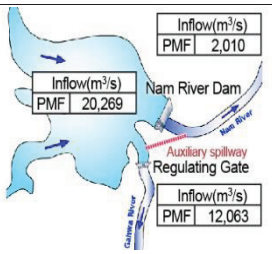
  As an alternative to further discharge in the direction of the Nam River, a tunnel-type auxiliary channel was established to increase the discharge capacity of the Nam River Dam.

- Case 4 : Increased distribution of discharges in Nam River and Gahwa stream(Case 2 + Case 3)

  It is a plan to apply the Nam River and Gahwa stream's allocation discharged to 1: 6 for the increased flood volume by establishing the tunnel-type auxiliary spillway on the Nam River side and improve the existing regulating gate on the Gahwa stream side. At this time, the plan was additionally reviewed to change M.W.L. on the safety side that does not overflow the dam as a non-structural measure apart from the facility plan.

Results of the proposal planning and hydrological safety review for each of the alternatives are shown in the Table 3.

**Table 3** : Measures to increase hydrological safety of Nam River Dam

| Item | Case 1 : Dam height increase | Case 2 : Gahwa stream Discharge increase | |
|---|---|---|---|
| | | Build the auxiliary Spillway | Add of the regulating gate |
| Facility plan | ▪Dam crest (EL.51.0m→EL.53.6m) | ▪B12.6m×H10.5m×6ea | ▪B8.0m×H16.3m×6eae |
| Distribution discharge |  |  |  |
| Item | Case 3 : Nam River stream Discharge increase | Case 4 : Increased distribution of discharges in Nam River and Gahwa stream(Case 2 + Case 3) | |
| | | Maintain M.W.L | Change M.W.L |
| Facility plan | ▪Auxiliary Spillway<br>-Tunnel : D15.3m×3row) | ▪Auxiliary Spillway<br>-Tunnel : D12.1m×1row)<br>▪Add of the regulating gate<br>-B8.0m×H16.3m×5ea | ▪Auxiliary Spillway<br>-Tunnel : D11.0m×1row)<br>▪Add of the regulating gate<br>-B8.0m×H16.3m×4ea)<br>▪ Raising parapet wall<br>-H0.7m×L1,126m |
| Distribution discharge |  |  |  |

## 3.3 Plan of the discharge through facilities

### 3.3.1 *Flood control and facility specifications*

In order to optimally enforced capacity of flood control in the Nam River Dam, we adopted the auxiliary spillway was established in the direction of Nam River and regulating gate was expanded in the direction of Gahwa stream by complying with the ratio 1: 6, which is the distribution ratio of Nam River and Gahwa stream, the discharge standard of the existing dam in P.M.F..

By increasing the discharge capacity and changing the maximum water level of the dam as a non-structural measure, the safety of the dam could be secured by installing a parapet wall to secure the clearance within the range where the reservoir level does not overtake the dam body.

The basic direction of dam operation during flooding is to control and discharge the inflow flood by using the reservoir space between the N.H.W.L.(normal high water level, or restricted reservoir water level in flood period) and the F.W.L(Flood water level), thereby reducing downstream flood damage and stably maintaining various waters after the flood period. It should be ensured that there is sufficient reservoir capacity to supply.

The operation plan for flood control during P.M.F. invasion through Nam River Dam's flood control project is as Table 4.

**Table 4** : Flood Control Operation of Nam River Dam

| Item | | Dam construction | At this time of analysis | Distribution |
|---|---|---|---|---|
| Operation Method | Less than H.W.L | Rigid ROM<br>(Constant amount controlled discharge)<br>Nam River 800m$^3$/s, Gahwa stream 3,250m$^3$/s | | Nam River :<br>Gahwa stream<br>= 1:4 |
| | More than H.W.L | Rigid ROM | Full Open | Nam River :<br>Gahwa stream<br>= 1:6 |
| Pre-release | | Apply | Apply | |
| Restricted reservoir water level | | Unapplied | Unapplied | |
| Normal High Water Level | | EL.41.00m | EL.41.00m | |
| Flood Water Level | | EL.46.00m | EL.46.00m | |
| Maximum Water Level | | EL.49.3m | EL.50.0m | |
| Maximum Outflow (P.M.F.) | | 7,000m$^3$/s<br>- Nam River 1,000<br>- Gahwa stream 6,000 | 14,073 m$^3$/s<br>- Nam River 2,010<br>- Gahwa stream 12,063 | |

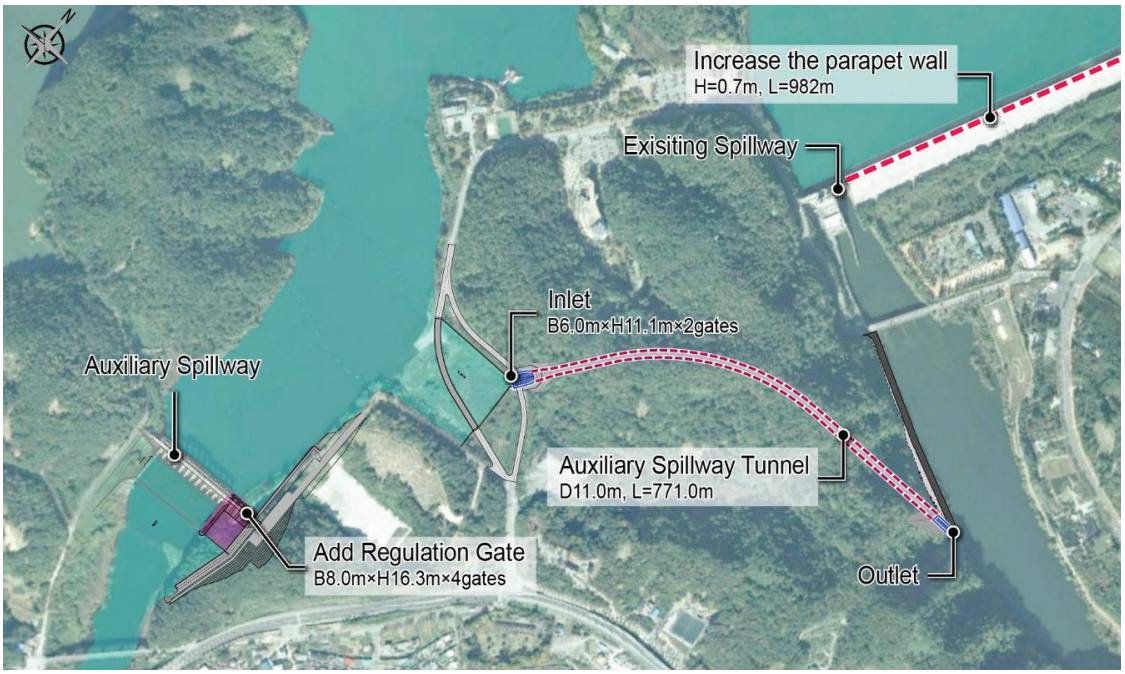


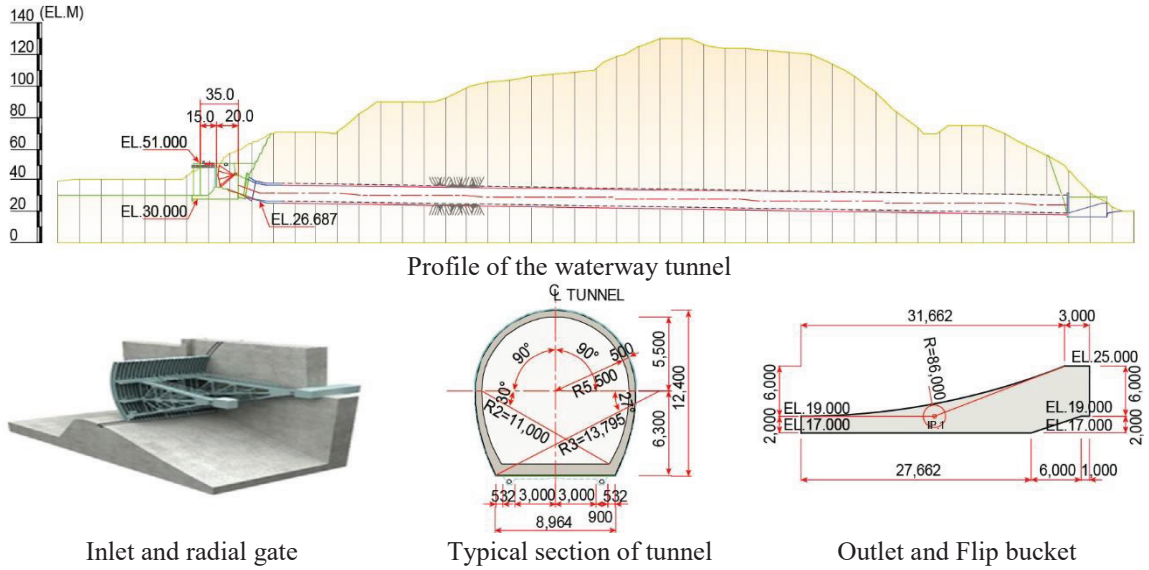

**Figure 4** : Layout in a measure of Dam safety of the Nam River Dam

**Table 5** : Specification of the discharge facilities (P.M.F.)

| Item | | Unit | Auxiliary Spillway | Add Regulation Gate |
|---|---|---|---|---|
| Approach channel | Width<br>Bottom EL.<br>Depth | m<br>EL.m<br>m | 16.0<br>30.0<br>6.0 | 48.0<br>26.0<br>4.0 |
| Weir | Width×Row<br>Crest EL.<br>Upstream slope<br>Downstream slope | m<br>EL.m | 6.0m×2<br>36.0<br>1 : 1<br>1 : 4 | 8.0m×4<br>30.0<br>Vertical<br>1:1.73 (30°) |
| Waterway tunnel | Length<br>Diameter<br>Tunnel slope | m m | 771<br>11.0<br>1:100 | – |
| Still water | Type<br>Length<br>Width<br>Lip EL. | <br>m<br>m EL.<br>m | Flip bucket<br>34.6<br>11.0<br>25.0 | Stilling basin<br>50.0<br>44.0<br>35.0 |

### 3.3.2 *The tunnel-type auxiliary spillway(on the Nam River side)*

Directly downstream of the Nam River Dam, Jinju-City has a developed city, and there are many limitations in the construction of the auxiliary spillway for this plan. Considering of the characteristics of Nam River Dam near the city center, it is desirable to avoid open channel-type spillway, which is a large facility that is operated only to minimize natural damage and to be limited to the disaster situation of P.M.F. A tunnel-type spillway has been adopted to minimize external exposure. In addition to the inlet part was selected for the land construction with topography above the N.H.W.L.(Normal high water level) considering the environmental and economic aspects and construction conditions. Therefore, it was selected as the valley part as close as possible from the discharge point of Nam River Dam. The tunnel main line section avoided the vulnerable valley part considering the tunnel depth based on the flow in and out part, and planned the route so that there was no separate facility for the alternative part in accordance with the flow direction of the Nam River main stream after discharge.




Profile of the waterway tunnel

Inlet and radial gate | Typical section of tunnel | Outlet and Flip bucket

**Figure 5** : Layout of the tunnel-type auxiliary spillway(on the Nam River side)

### 3.3.3 *Add a gates in the existing Regulating Gate(on the Gahwa stream side)*

Gahwa stream shares about 6 times more than the discharge of Nam River during P.M.F.. In order to examine the discharge capacity of the regulating gate, the construction of the auxiliary spillway, the addition of the waterway-type spillway in the right-hand side of the regulating gate and the add a gate beside the current regulating gate were reviewed. The decision was made to add four more gates, which are the same specifications as the current operating facilities.

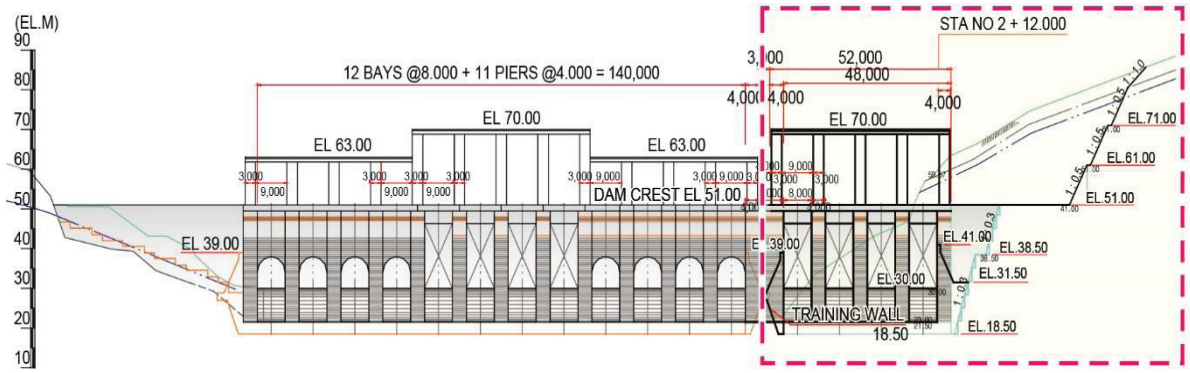



**Figure 6** : Layout of the add a gates(on the Gahaw stream side)

### 3.3.4 *The increase the parapet wall on the Nam River Dam*

In the hydrological safety review of the Nam River Dam, the Maximum water level by P.M.F. was EL.50.0m, and no dam overflow occurred.

Therefore, considering the 2.83m of dam clearance, the existing parapet wall height (EL.52.2m) was increased by 0.7m to ensure dam safety.

**Table 5** : Clearance(Hf) Check for Nam River Dam

| Item | | Height | Note |
|---|---|---|---|
| Clearance Formula | at Flood water level | $H_f \geq h_w + \frac{1}{2}h_e + h_a + h_i$ | $h_i$ = 1.0m(usually)<br>$h_a$ = 0.5m(gate O) |
| | at Maximum water level | $H_f \geq h_w + h_a + h_i$ | |
| Considering Factor | significant wave height, $h_w$(m) | 1.33 | $h_i$ : Safety height (Dam type usually 1m)<br>$h_a$ : Safety height (gate O = 0.5m) (gate X = 0m) |
| | Wave length, L(m) | 19.90 | |
| | Wave height by the earthquake, $h_e$(m) | 0.29 | |
| Clearance ($H_f$) | at Flood water level(m) | 2.98 | |
| | at Maximum water level(m) | 2.83 | |
| Dam crest elevation(EL.m) | | 51.0 | |
| Allowable maximum water level Check(EL.m) | | 49.37 < 50.0(M.W.L) N.G<br>(EL.51.0m + 1.2m - 2.83m) | existing parapet wall H=1.2m |
| Request parapet wall crest elevation(EL.m) | | 52.9<br>(EL.50.0m + 2.83m) | improved parapet wall H=1.9m |

Parapet Wall's structural form compares the method of reinforcement of the existing parapet wall and the construction of the parapet upper tempered glass in order to secure the landscape element and the view right. We chose to install tempered glass on top by reinforcing existing parapet wall.

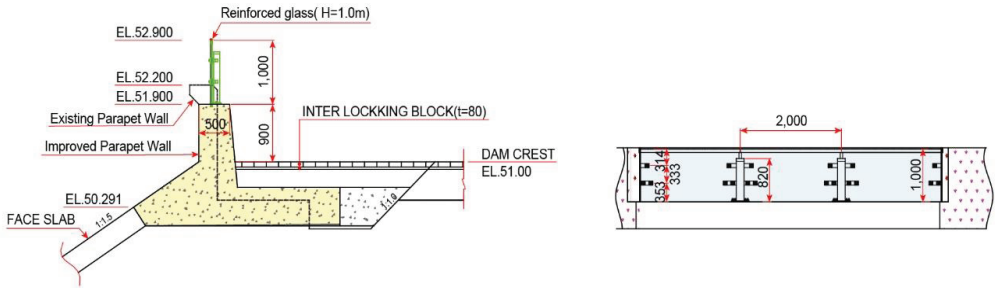


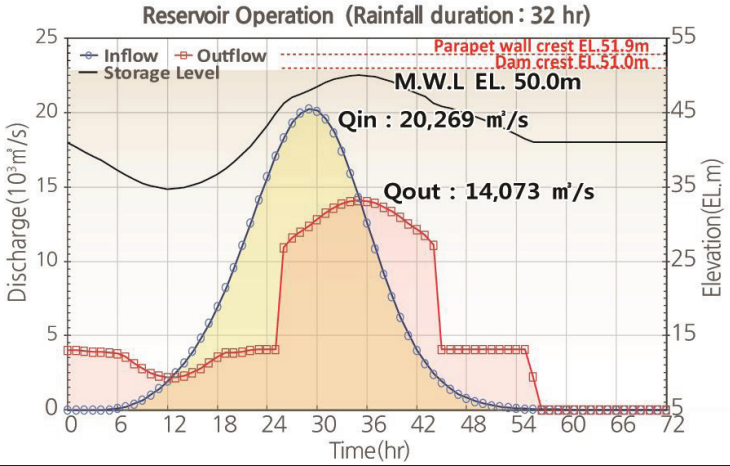

**Fig. 7** : Layout plan of reinforcing in existing parapet wall

## 3.4 Conclusions

Nam River Dam is a multi-purpose dam with weak safety due to the recent increase in design flood due to climate change, the maximum water level in the dam overtakes the dam and leads to the collapse of the dam. Therefore, it was possible to secure hydrological safety by applying structural measures together with non-structural measures to secure dam safety.

The hydrological safety results from the reservoir routing of the present and post-Nam River dams are shown in the table below.

**Table 6** : Evaluation of Hydrological Safety in Nam River Dam

| Item | Before(Existing Dam) | | | | | | After(Enforcement Dam) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Rigid ROM | | | Full Open | | | | | |
| | Inflow (㎥/s) | Outflow (㎥/s) | M.W.L (EL.m) | Inflow (㎥/s) | Outflow (㎥/s) | M.W.L (EL.m) | Inflow (㎥/s) | Outflow (㎥/s) | M.W.L (EL.m) |
| Discharge & Water level | 19,596 | 7,000 | 53.23 | 19,596 | 10,371 | 51.86 | 20,269 | 14,134 | 50.00 |
| Reservoir Operation (Enforcement Dam) |  | | | | | | | | |

Nam River Dam is a multi-purpose dam that builds and operates an artificial spillway to reduce flooding at the mainstream of the Nam River. Therefore, this task aimed to contribute to flood control safety of the Nam River Dam by adjusting the interests of the two regions and establishing the best way to satisfy each other.

Nam River Dam is a multi-purpose dam that constructs and operates flood control channel, artificial waterways, to reduce flooding in the main stream of the Nam River, and despite the urgent need to secure dam safety, the project has been delayed due to regional conflicts over the amount of discharge and allocation of the downstream stream.

This plan was intended to contribute to securing flood control safety of the Nam River Dam by adjusting the interests between the two regions and establishing optimal measures to satisfy each other.