DETERMINATION OF EXISTING DAM EXCAVATION EXTENTS USING FESWMS-2DH

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ABSTRACT: The new Namkang Dam near the downstream of the old Namkang Dam in Korea is constructed to provide more water-supply to the cities. So the old Namkang Dam should be removed. The purpose of this study is to determine the excavation extents, considering an approach flow into new dam spillway and a dam removal construction cost, of the old Namkang Dam using a numerical simulation. The Finite Element Model, FESWMS-2DH (2-D Depth-Integrated Finite Element Surface Water Modeling System), is applied to the old Namkang Dam reservoir area extending to the new Namkang Dam and its spillway. The reservoir peak inflow discharges and the corresponding reservoir levels for the 200-year frequency flood and probable maximum flood (PMF) are used to define the boundary conditions of the Finite Element Model. The flow through the spillway of new Namkang Dam is mainly depending on the spillway capacity and the reservoir volume. Since the inflow boundary of the model is located at a large distance upstream from the new Namkang Dam and the by-pass flow accounts for about 75% of the total inflow, the condition of the spillway approach flow is not sensitive to the inflow condition specified, and no further refinement of this boundary condition is necessary. A total of six alternative excavation schemes for the old Namkang Dam have been analyzed for both flood conditions. Two excavation depths for partial removal of the old dam to El. 34-m (original plan) and El. 42-m respectively and three widths (100-m, 200-m, and 300-m) of the deep excavation section at the old spillway and powerhouse are considered in the study. The results indicate that, under the 200-year frequency flood condition, the alternative excavation plan with the crest elevation of the old dam lowered to El. 42-m provides better approach flow condition. There will be less flow over the submerged old dam and more flow will pass through the deep excavation section. As more flow passes through the deep cut opening, a more concentrated flow approaching the spillway will be formed. Such arrangement provides an invisible guide wall effect and the approach flow condition is improved. The spillway approach flow condition can be improved by selecting a proper combination of excavation depth of the old dam and the width of the deep excavation section at the old spillway and powerhouse. (Key words: dam spillway, dam removal, excavation, PMF, FESWMS-2DH)

INTRODUCTION

The assessment of the old Namkang Dam excavation schemes with respect to the spillway approach flow condition is studied. The spillway approach flow study is performed for the determination of an excavation scheme of the old Namkang Dam that would yield smoother spillway approach flow condition for more efficient conveyance of water at the spillway and powerhouse.

The new Namkang Dam, spillway and powerhouse are located at a short distance downstream of the old Namkang Dam at the west of Jinju City as shown in Figure 1.

Figure 1 - Location of New and Old Namkang Dams

The left abutment is located at 100 meters downstream of the old dam and 400 meters for the right abutment as shown in Figure 1. The new Namkang Multipurpose Dam is a Concrete Face Rockfill Dam (CFRD) which is 34-m high, 1,033-m long, and has a total fill volume of about 1.37 x 106 m3. Both upstream and downstream faces of the dam have a side slope of 1.5 H : 1.0 V on . Pertinent data for the new Namkang Dam are as follows:

Reservoir

- River system: Namkang River
- Catchment's area : 2,285 Km^2
- Mean annual rainfall: 1,416.8 mm
- Mean annual runoff: 64.4 m^3/sec
- Probable Maximum Flood (PMF) water level: 49.3 m
- 200-yr frequency flood water level: 46.0 m

- Normal maximum water level: 41.0 m

Storage Capacity

- Gross storage capacity: 309.2 x 106 m^3
- Active storage capacity: 299.7 x 106 m^3
- Dead storage capacity: 9.5 x 106 m^3
- Flood control capacity: 269.8 x 106 m^3

Flood Related Discharges

- Design flood: 10,400 m^3/sec
- Spillway design discharge: 800 m^3/sec
- Discharge through diversion weir in Sachun spillway: 3,250 m^3/sec

Estimated Reservoir Peak Flood Inflows

- 200-year frequency flood: 3,460 m^3/sec
- PMF: 4,900 m^3/sec

Dam

- Type: Concrete Face Rockfill Dam (CFRD)
- Height: 34.00 m
- Crest elevation: 51.00 m
- Crest length: 1,033.50 m
- Crest width: 7.50 m
- Total fill volume: 1.369 x 106 m^3
- Spillway total width: 27.00 m
- Intake width: 28.00 m
- Top of parapet: 52.20 m
- Side slopes (u/s and d/s): 1.5 H : 1.0 V

Spillway

- Location: between CFRD and intake structure
- Type: Orifice
- Gate: Roller gate (6.4 m x 5.4 m): 3 sets
- Peak operating outflow discharge:
    - 200-year frequency flood: 800 m3/sec
    - PMF: 1,000 m3/sec

Powerhouse

- Location: Right bank of dam

- Installed capacity: 14,000 Kw (7,000 Kw x 2 units)
- Type of turbine: Bulb type
- Rated effective head: 16.00m
- Tailwater level: EL. 21.70 m
- Annual energy output: 41.30 Gwh
- Discharge capacity: 100 m^3/sec

Based on a previous study, the attenuated peak flood inflow discharges at the new Namkang Dam reservoir are estimated to be about 3,460 cms for the 200-year frequency flood and 4,900 cms for the Probable Maximum Flood (PMF). The corresponding maximum reservoir levels at the new Namkang Dam reservoir are respectively El. 46.0 m and 49.3 m. The subject spillway is located at the right side of the new embankment dam. To assess the effect of the partial removable of the old dam on the approach flow condition of the new spillway, a two-dimensional depth-averaged finite element flow model is constructed for analyzing the conditions of the approach flow toward the spillway.

The results of the flow analysis provide information such as water levels, velocities and the approach flow patterns for the assessment of the old dam excavation schemes with respect to the efficiency of the spillway approach flow conveyance. The model provides water-column averaged velocities and water surface elevations. The computed velocities are presented in graphic form showing velocity vectors at the computational nodal points. These velocity vectors show general flow pattern in the reservoir and the spillway approach area.

NUMERICAL MODELING

The model is developed based on the two-dimensional depth-integrated finite element flow analysis computer program, FESWMS-2DH (2-D Depth-Integrated Finite Element Surface Water Modeling System). The program is developed by the U.S. Geological Survey for the U. S. Federal Highway Administration for assessment of two-dimensional flow condition at a bridge crossing and for assessment of bridge pier scour potential. The model solves the two-dimensional shallow water wave equations and can be applied to simulate surface water system such as reservoirs, open-channels, and coastal water.

This finite element model is applied to old Namkang Dam reservoir area extending from the new spillway/dam as the downstream boundary to approximately 1,400 meters upstream of the new dam as the upstream boundary. The reservoir peak inflow discharges and the corresponding reservoir levels for the 200-year frequency flood and PMF are used to define the boundary conditions of the finite element model. The flow through the spillway of the new Namkang Dam is mainly depending on the spillway capacity and the reservoir volume. Sine the inflow boundary of the model is located at a large distance upstream from the new dam and the by-pass flow accounts for about 75% of the total inflow, the condition of the spillway approach flow is not sensitive to the inflow condition specified, and no further refinement of this boundary condition is necessary.

To perform the finite element analysis of the flow in the reservoir, the following information is used.

- Hydrologic data, such as the flood inflow hydrographs for the 50-year, 100-year, 200-year, and probable maximum flood (PMF) event
- Orifice spillway discharge rating curve
- Reservoir cross-section survey data for the reservoir area starting from the new spillway and the new Namkang Dam to approximately 1,000 meters upstream from the old Namkang Dam at approximately 200 meter intervals
- Powerhouse unit discharges
- Data for the old dam and spillway removal after construction

Based on a previous study, the attenuated peak flood discharges at the new Namkang Dam reservoir is estimated to be about 3,460 cms for the 200-year frequency flood and 4,900 cms for the PMF. The corresponding maximum reservoir levels at the Namkang dam are respectively El. 46.0 m and 49.3 m. They are used to define the boundary conditions of the finite element model of the new Namkang dam reservoir. The flow near the spillway depends mainly on the spillway discharges and old dam excavations. That is the flow condition in the vicinity of the spillway approach area is not sensitive to the inflow condition specified at the upstream inflow boundary of the model, and no further refinement of this boundary condition is necessary.

Six excavation schemes of the old dam are investigated for the 200-year frequency and probable maximum flood conditions. The study includes investigation of the effect of the excavation depth of the old dam and the width effect of the deep excavation section at the old spillway and powerhouse on the approach flow conditions. Two dam crest elevations of the partially removed old dam are investigated. They are EL. 42 m and EL. 34 m. Three different widths of the deep excavation section are investigated. They are respectively 100 m, 200 m, and 300 m. For each excavation scheme investigated, both 200-year frequency and PMF floods are considered. A total of 12 cases are analyzed as given in Table 1 and Table 2.

Table 1 - Simulation Cases for the Old Dam Excavation Extent Determination (200-year Frequency Flood Event)

Simulation Cases	Crest Elevation of Old Namkang Dam	Width of Deep Cut Excavation Section for Old Namkang Dam Spillway/Powerhouse	Flood Conditions
1	EL. 34 m	100 m	200-year Flood
2	EL. 34 m	200 m	200-year Flood
3	EL. 34 m	300 m	200-year Flood
4	EL. 42 m	100 m	200-year Flood
5	EL. 42 m	200 m	200-year Flood
6	EL. 42 m	300 m	200-year Flood

Table 2 - Simulation Cases for the Old Dam Excavation Extent Determination (Probable Maximum Flood Event)

Simulation Cases	Crest Elevation of Old	Width of Deep Cut	Flood Conditions

	Namkang Dam	Excavation Section for Old Namkang Dam Spillway/Powerhouse	
1	EL. 34 m	100 m	PMF
2	EL. 34 m	200 m	PMF
3	EL. 34 m	300 m	PMF
4	EL. 42 m	100 m	PMF
5	EL. 42 m	200 m	PMF
6	EL. 42 m	300 m	PMF

SIMULATION RESULTS

The reservoir bottom elevations as incorporated in the finite element models are depicted in color-filled contour plots. These plots show six excavation schemes investigated in this study. The constructed finite element mesh is presented. The same mesh is used for all excavation schemes. The bottom elevations along the old Namkang Dam are changed in accordance with the excavation scheme being investigated.

The results of the spillway approach flow analysis into new Namkang Dam spillway are presented in vector and color-filled contour plots. For each case, velocity and unit flow vectors are plotted in three different scales, namely global, regional and local, for easier visualization of the simulated flow patterns. The plots in global scale include the by-pass flow through main Namkang River channel. The flow patterns of the flow over the partially removed old dam can be reviewed on the regional scale, and the flow patterns of the approach flow at the spillway are best presented in the local scale. The unit flow is the unit discharge at a given point (node) and is defined as the product of the computed column-averaged velocity and the flow depth at the nodal point. The effects of the excavations on the spillway approach flow conditions can easily visualized with the color-filled contour plots especially based on the computed unit flows. In addition, summary color plot of unit flow distributions are presented for the 200-year frequency flood condition and for the original and the alternative excavation schemes. Well defined approach flows can be seen in the unit flow plots for the alternative excavation schemes.

A total of six cases have been analyzed for a 200-year frequency flood event (200-year flood). The six cases are developed using two different excavation depths (to El. 34 m and 42 m respectively) and three different widths of deep excavation section at the old spillway and powerhouse. The vector plots for Simulation Cases are shown in the figures. The figures are a global velocity vector plot, a global discharge vector Plot with unit flow, a regional velocity vector plot, a regional discharge vector plot with unit flow, and a local velocity vector plot near spillway and intake structure. The unit flow and velocity distributions are also presented in color-filled contour plots for easier visual review of the results. Similar set of plots for the remaining cases are also provided.

Most (about 75%) of the inflow to the reservoir area follows the main channel of the Namkang River and discharges into the Sachun Bay through the Sachun Bay spillway as bypass flow. The simulation results indicate that the new Namkang Dam reservoir behaves as a level pool, due to

relatively small discharges withdrawn by the spillway and powerhouse. That is, discounting the wind effect, the water surface elevation would vary insignificantly in the reservoir area.

The flow that enters the reservoir and passes over the submerged excavated old dam toward the spillway originated from approximately 25% of the inflow on the left bank side at the inflow boundary of the model. The interface between the bypass flow and the spillway/powerhouse through-flow would terminate on the right bank of the reservoir at a distance about 250 meters upstream from the old powerhouse. The trajectory of this interface and the location of the termination point do not change appreciably with respect to flow conditions investigated in this study.

Two excavation depths are investigated. The crest of the old dam lowered to El. 34-m (original plan) and El. 42-m respectively are investigated. The results indicate that the alternative excavation plan with the crest of the old dam at El. 42 m provides better approach flow condition. There will be less flow over the submerged old dam and more flow passing through the deep cut section at the old spillway/powerhouse. More flow will be forced to pass through the deep cut opening and forming a more concentrated flow approaching the spillway. Such arrangement provides an invisible guide wall effect and the approach flow condition is improved.

Three different widths of the deep cut section at the old spillway are investigated. They are 100, 200 and 300 meters respectively. The 100-meter wide cut is too narrow that would force more water to flow over the submerged old Namkang Dam and, therefore, more flow to approach the spillway along upstream face of the new Namkang Dam and increase the tendency for the flow to separate when it passes the wind wall at the spillway. A deep excavation section of 200 to 300 meters wide at the old spillway would provide the best approach condition.

A relatively small and weak circulation eddy would form on the reservoir side of the wing wall at the intersection of the wing wall and the new dam. No significant trapping of floating debris is expected. A cross flow from the reservoir near the new Namkang Dam flowing over the wing wall into the approach channel at the spillway entrance is expected. With an improved alternative excavation plan, this cross flow does not appear strong enough to cause a significant separation problem when it enters the spillway entrance channel. The simulated flow pattern and the velocities at the spillway entrance channel agree well with the previous physical model study conducted in Korea National Construction Laboratory in October, 1989. For the 200-year frequency flood condition with the original excavation plan, the simulated flow pattern and the velocities at the spillway entrance channel excellent agreement with the previous physical model study conducted in Korea National Construction Lab in October, 1989.

SUMMARY / CONCLUSION

For the approach flow analysis, the finite element surface water modeling program FESWMS-2D is applied and a total of six alternative excavation schemes have been analyzed for the 200-year frequency flood and probable maximum flood (PMF) conditions. Two excavation depths for partial removal of the old dam to El. 34-m and El. 42-m respectively and three widths (100-m, 200-m, and 300-m) of the deep excavation section at the old spillway and powerhouse are considered in the study.

Most of the inflow to the new Namkang Dam reservoir area follows the main channel of the Namkang River and discharges into the Sachun Bay through the Sachun Bay spillway as bypass flow.

The simulation results indicate that the new Namkang Dam reservoir behaves as a level pool, due to relatively small discharges (in comparison with the bypass flow) withdrawn by its spillway and powerhouse. That is, discounting the wind effect, the water surface elevation would vary insignificantly in the reservoir area.

The spillway approach flow condition can be improved by selecting a proper combination of excavation depth of the old Namkang Dam and the width of the deep cut at the old Namkang Dam spillway and powerhouse. The alternative excavation plan with the crest of the old dam at El. 42 m provides better approach flow condition. A deep excavation section of 200 to 300 meters wide at the old Namkang Dam spillway would provide the best approach condition.

The views expressed herein do not necessarily represent the views of the Federal Energy Regulatory Commission or of the United States of America.

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