Numerical Simulation of 3D Debris Flow incurred by Reservoir Failure

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Contents

Introduction

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- In the 20th century, more than 200 dam failures occurred worldwide, and more than 11,000 casualties were incurred.

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Introduction

- In Korea, two-thirds of the annual rainfall is concentrated in the summer months. and localized heavy rains are frequent.
- Since 61, About 100 cases of dams and reservoirs collapses have been reported.

Reservoir	Year	Casualties	재산피해
Hyogi	1961	110 dead 57 missing 9,800 displaced	More than 190 Houses
Gudeok	1972	60 dead 15 missing 48 injured	-
Sandae	2013	-	1.2ha Farmland 13 Vehicles 5 Houses 6 Malls

- Among the 76 reservoirs of D grade in 2018, 64 in D grade in 2019.
  (Grade D: requiring urgent repair, reinforcement, or restrictions on use)

Predicting the damage and prioritizing the maintenance ranking using numerical analysis

Introduction

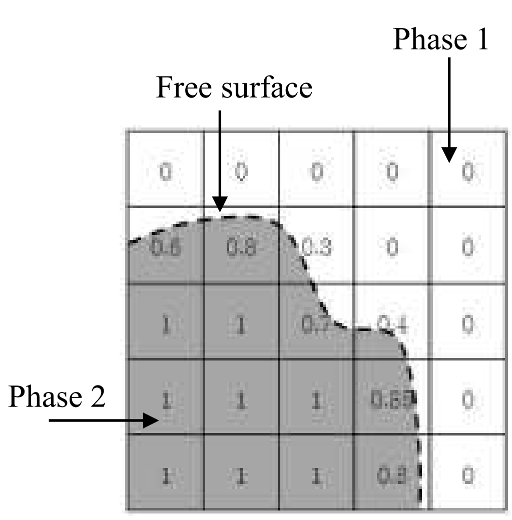
- Experimental Study
  - 단순화된 2D 단면 형상 댐 붕괴 실험 및 고정된 수로에서 수행됨
  - Terrain slope cannot be considered.
- Numerical Simulation Study
  - 2D Numerical Model Utilization such as FLO-2D, DAMBRK.
  - Does not take into account the effects of debris flow.
  - The limitation of the 2d model : analysis of the initial rapid current collapse.

Purpose → **Development of Numerical Model for Reservoir Failure by 3D Multiphase Flow Analysis Considering Real Terrain and Debris Flow.**

Computational Method

Governing Equation & Computational Method

- OpenFOAM
- Unsteady, Incompressible Navier-Stokes Eq.
- Multiphase Flow Analysis : Air, Water, Debris
- Applying VoF(Volume of Fluid)
- Nonlinear Viscous Fluid



$\rho = \alpha_1\rho_1 + \alpha_2\rho_2 \qquad \mu = \alpha_1\mu_1 + \alpha_2\mu_2 \qquad \alpha_2 = 1 - \alpha_1$

- Continuity Eq. $\nabla \cdot U = 0$
- Momentum Eq. $\frac{\partial U}{\partial t} + \nabla \cdot (UU) - \nabla \cdot (\nu \nabla U) = - \nabla P + \rho g + F_\sigma$
- Transport Eq.

$$\frac{\partial \alpha}{\partial t} + U\nabla\alpha = 0$$

$$\frac{\partial \alpha}{\partial t} + \nabla(\alpha U) + \nabla[U_r\alpha(1-\alpha)] = 0$$

Debris Flow Property - Nonlinear Viscous Fluid

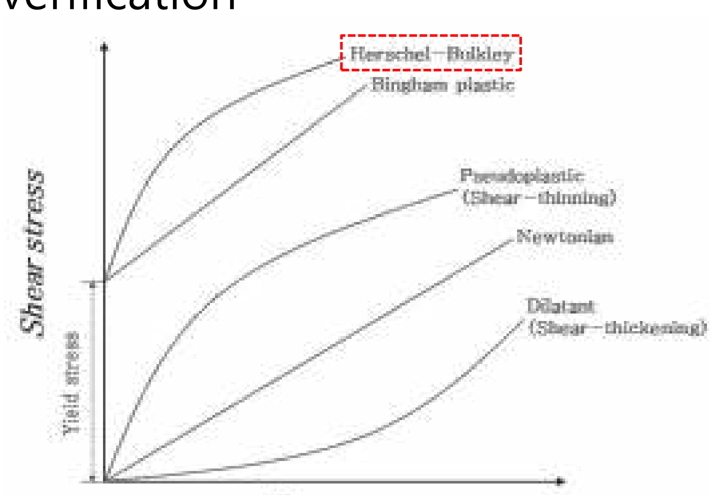
- Modified Herschel-Bulkley
  - Considering composition ratio and water content of soil
  - Shear stress determined by the water content
  - Calculation of parameters by experimental verification

$$\tau = \tau_y + k\dot{\gamma}^n$$

$$\tau_y = \tau_0 C^2 e^{22(CP_1)}$$

$$\tau_0 = \begin{cases} \tau_{00} Pa & C \le 0.47 \\ \tau_{00} e^{5(C-0.47)} & C > 0.47 \end{cases}$$

$$P_1 = \begin{cases} P_1 & P_1 \le 0.25 \\ 0.27 P_1 & P_1 > 0.25 \end{cases}$$



- Coulomb-viscoplastic
  - Consideration of friction angle of soil during viscous flow

$$\mu = \mu_{min} + \frac{P \cdot \sin(\delta)}{||D||}\left[1 - e^{-m_y||D||}\right]$$

Validation

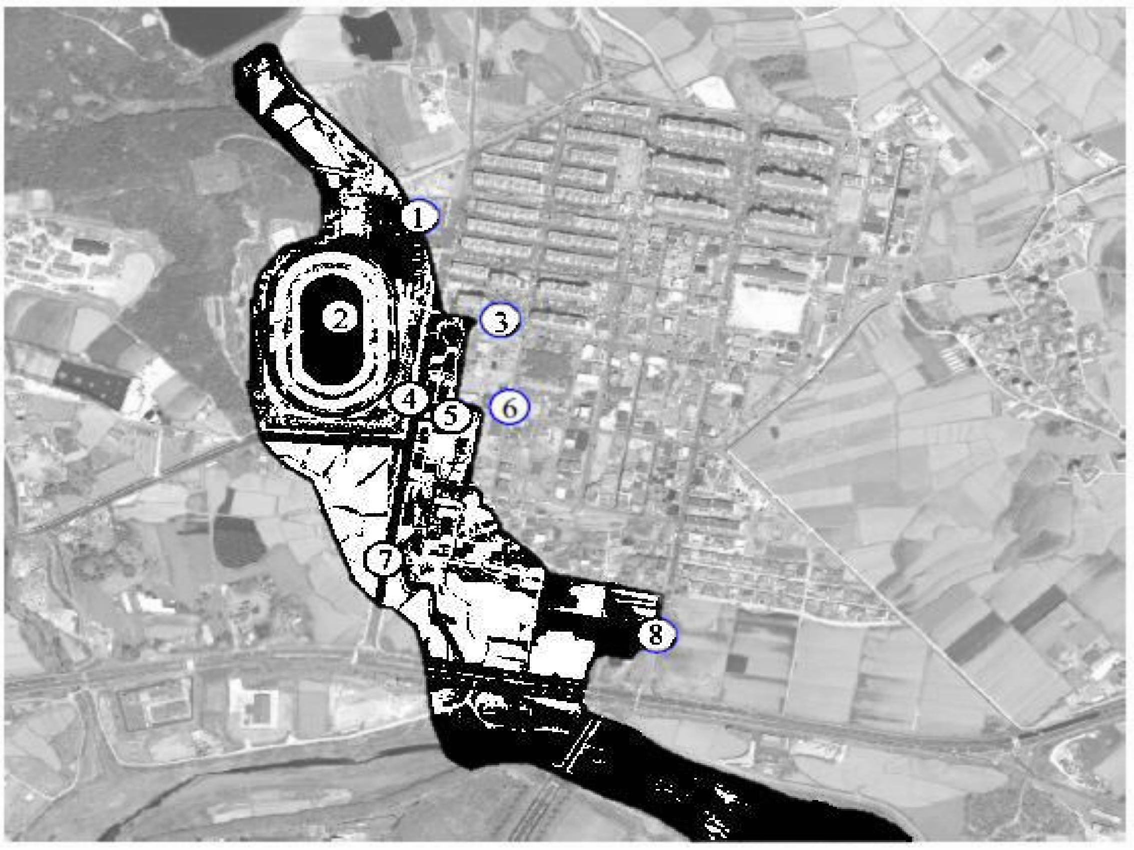
Selection of Reservoir to be Verified: Sandae

- **Date and Time**: 2013. 4. 12(Fri) 14:00
- **Site**: Angang-eup, Gyeongju-si, Gyeongsangbuk-do, Republic of Korea
- **Cause of Damage**: Embankment collapse(L=10m, H=8m) due to soil erosion caused by leak of channel, Accidents occurred while preparing for a precision diagnosis as the D grade was determined in the safety inspection(`13. 3. 12).
- **Action status**: Low-lying resident evacuation(100 people), Emergency recovery, Maintenance around flooded areas, etc.

Flooding Mark of the Sandae Reservoir

Go et al(2015)

Estimated damage area : 177,750m²



Lee et al(2015)

Estimated damage area : 394,513m²

* Estimated damage area : Survey and field survey

선행 해석 연구

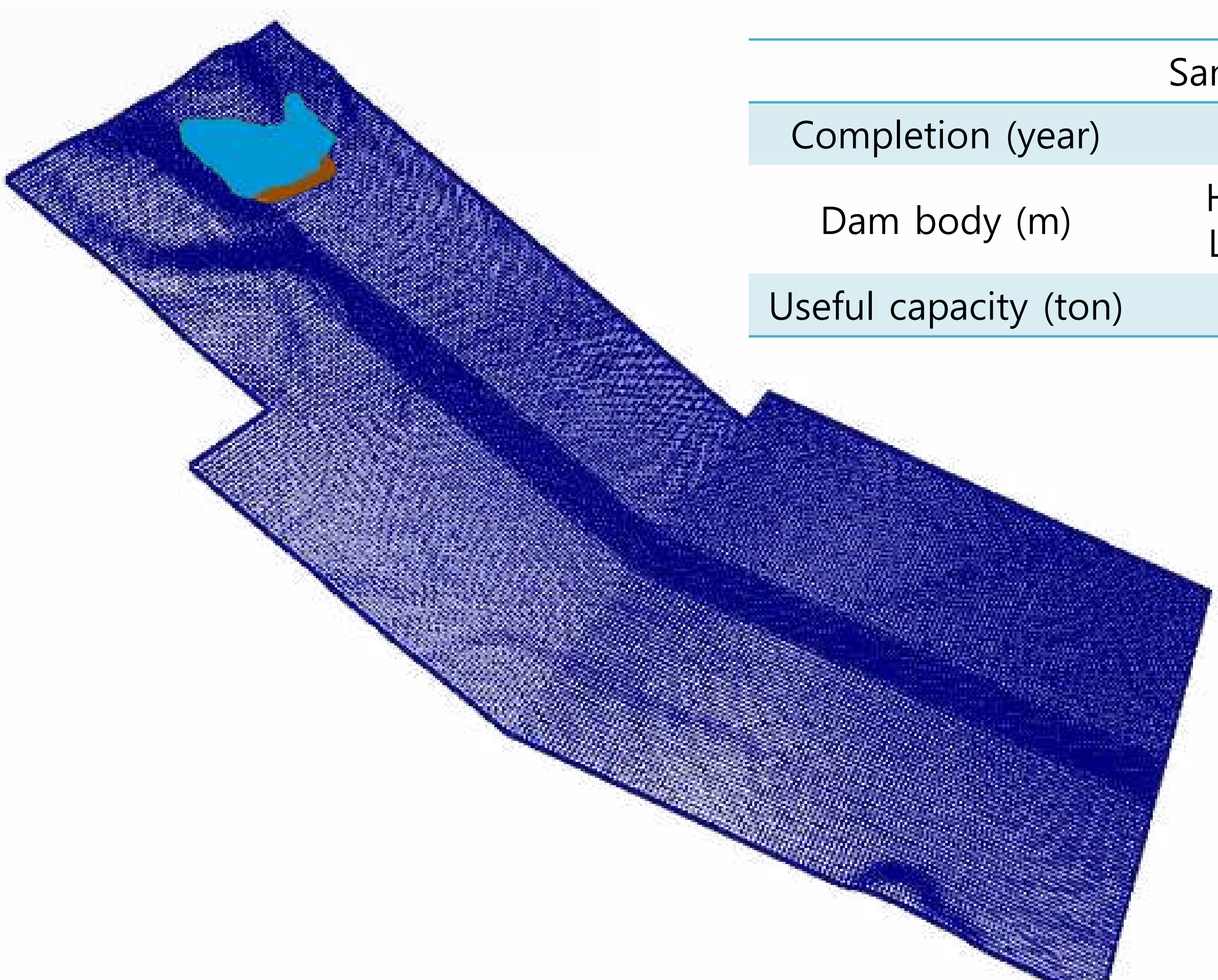
Go et al(2015)

- Numerical model : FLO-2D
- Number of grid : 50,693개
- Damage area as a result : 196,400m^2
- Total damage area flood time: 20min

Lee et al(2015)

- Numerical model : FLO-2D
- Number of grid : 218,091개
- Damage area as a result : 355,005m^2
- residential areas flood time: 20~30min
- Added building layers extracted from satellite data

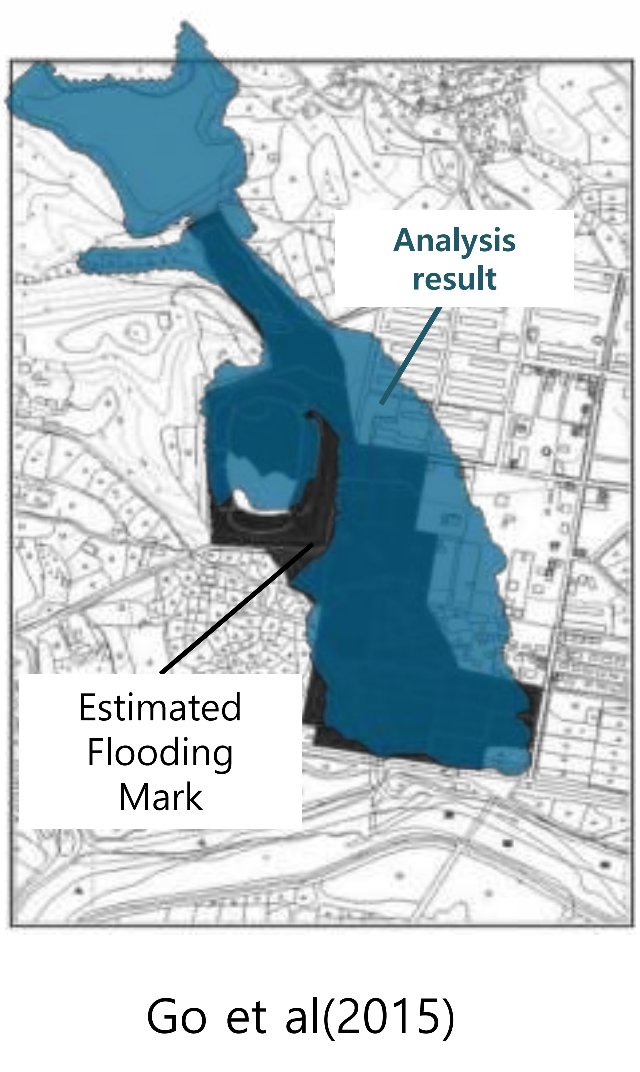
Computer Modeling – Sandae Resevoir



	Sandae resevoir
Completion (year)	1964
Dam body (m)	Height 12.2 Length 210
Useful capacity (ton)	245,000

Analysis result – Sandae Resevoir

Comparison of Flooding Mark - Sandae Reservoir



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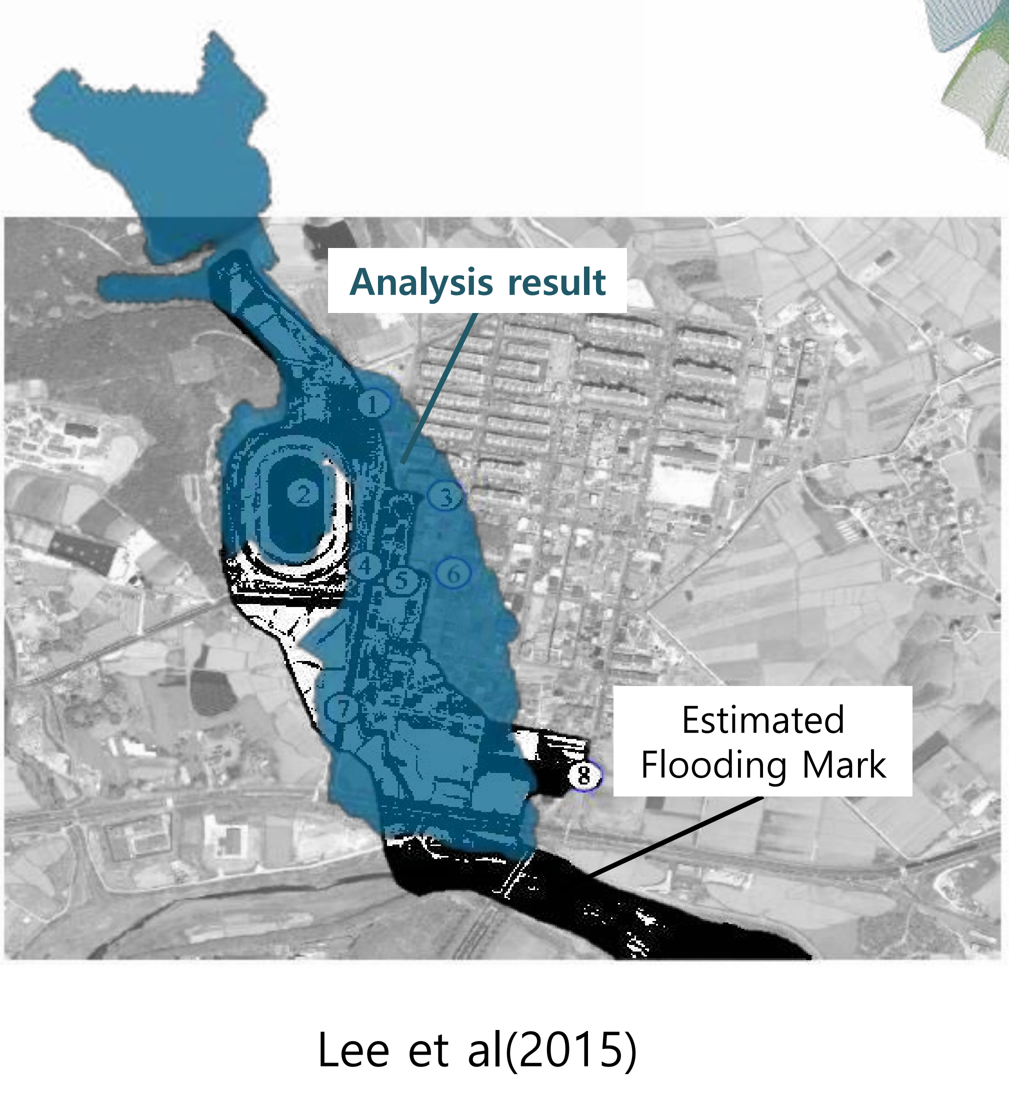

Lee et al(2015)

Analysis Results

Similar Reservoir

Analysis Case

	Neungcheon resevoir	Sanmak resevoir	Jeosa resevoir
Completion (year)	1945	1945	1983
Dam body (m)	Height 7.2 Length 122	Height 10.6 Length 131	Height 20 Length 71
Useful capacity (ton)	70,650	54,100	55,000

※ Assumption of entirety dam failure

Analysis Results
-Neungcheon resevoir

Analysis Results
-Sanmak resevoir

Analysis Results
-Jeosa resevoir

Conclusion

Conclusion

- Limits of 3D Realization of Collapse Analysis and the Reflection of Debris Effects in the Early Collapse of the Fill Dam
- Development of 3D Flow Analysis Method Considering Multiphase Flow and Nonlinear Viscosity, Which are the Characteristics of Debris
- Simulation of Sandae Reservoir Collapse Results in Predicting more Accurate Flooding Range than Existing Methods
- Flood Range Forecast for Three Aging Reservoirs -Neungceon, Sanmak, Jeosa