Numerical Simulation of Debris Flow incurred by Earth Dam Collapse

Sungsu Lee, Joo Yong Lee, and Selugi Lee

Chungbuk National University
Rep. of Korea

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Introduction

- Concerns about dam and reservoir collapse due to heavy rains, sudden downpours and typhoons caused by global warming have increased.
- In the 20th century, more than 200 dam failures occurred worldwide, and more than 11,000 casualties were incurred.

▲ A CNN news story reporting a dam collapse in southeastern Brazil in Minas Gerais.

Introduction

- In Korea, two-thirds of the annual rainfall is concentrated during summer. and localized heavy rains are frequent.
- Since 1961, about 100 cases of reservoir breach have been reported.

Reservoir	Year	Casualties	Property damage
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

NEEDS for prediction of damage and prioritization of preparation by using numerical analysis

Previous Study & Present Study

- Experimental Study
  - Simplified 2D cross-section dam failure experiment and performed in a fixed channel
  - Terrain slope cannot be considered.

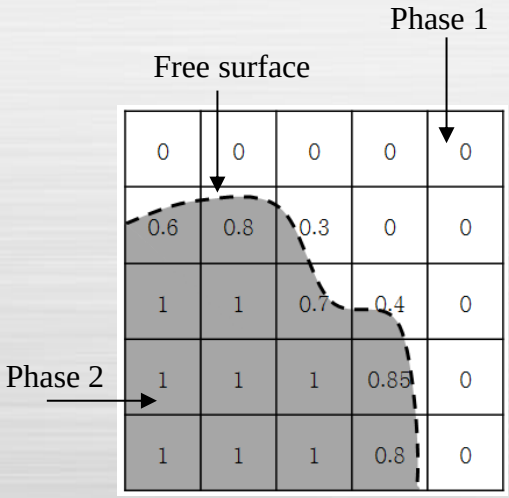
- Numerical Simulation Study
  - 2D Numerical Model Utilization such as FLO-2D, DAMBRK.
  - Does not take into account the effects of debris flow.
  - The limitation of the 2d model : analysis of the initial rapid current collapse.

Purpose

Development of Numerical Model for Reservoir Failure by 3D Multiphase Flow Analysis considering Terrain and Debris Flow.

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

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

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

Debris Flow Property - Nonlinear Viscous Fluid

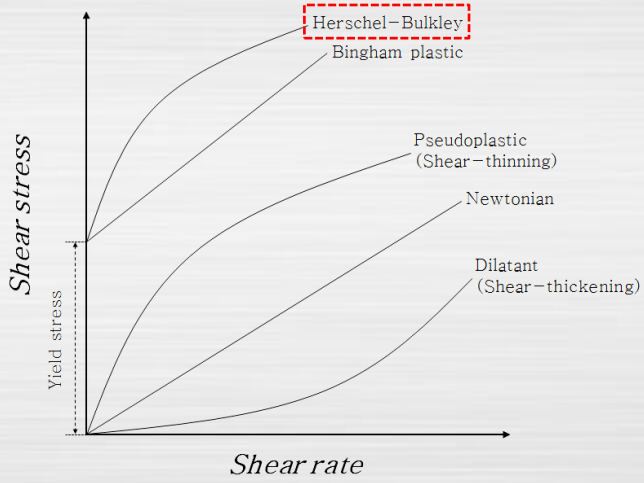
- Modified Herschel-Bulkley
  - Considering composition ratio and water content of soil
  - Shear stress determined by the water content
  - Calculation of parameters by experimental verification

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

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

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

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



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

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

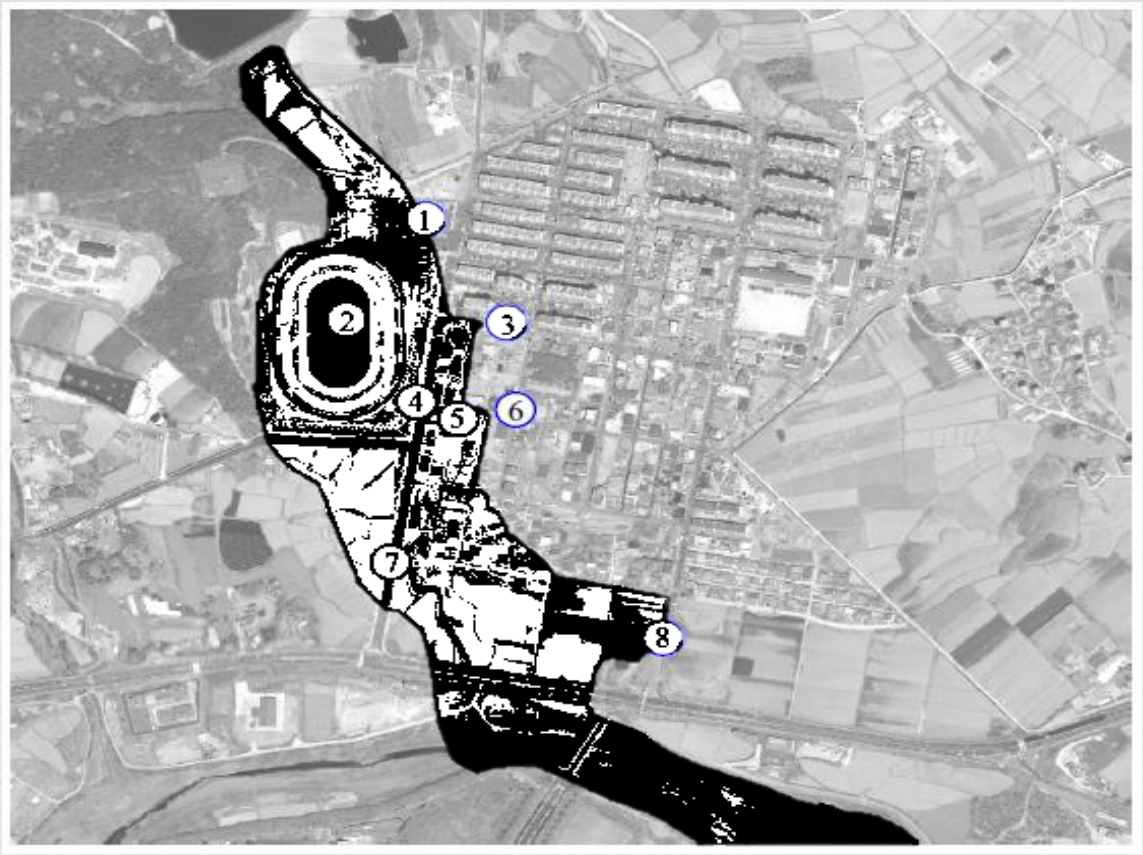
Application to Real Case of Sandae Reservoir Failiure

- **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
- **Action status**: Low-lying resident evacuation(100 people),
  Emergency recovery, Maintenance around flooded areas, etc.

Flooding Map of Field Survey

Go et al(2015)

Estimated damage area : 177,750m^2

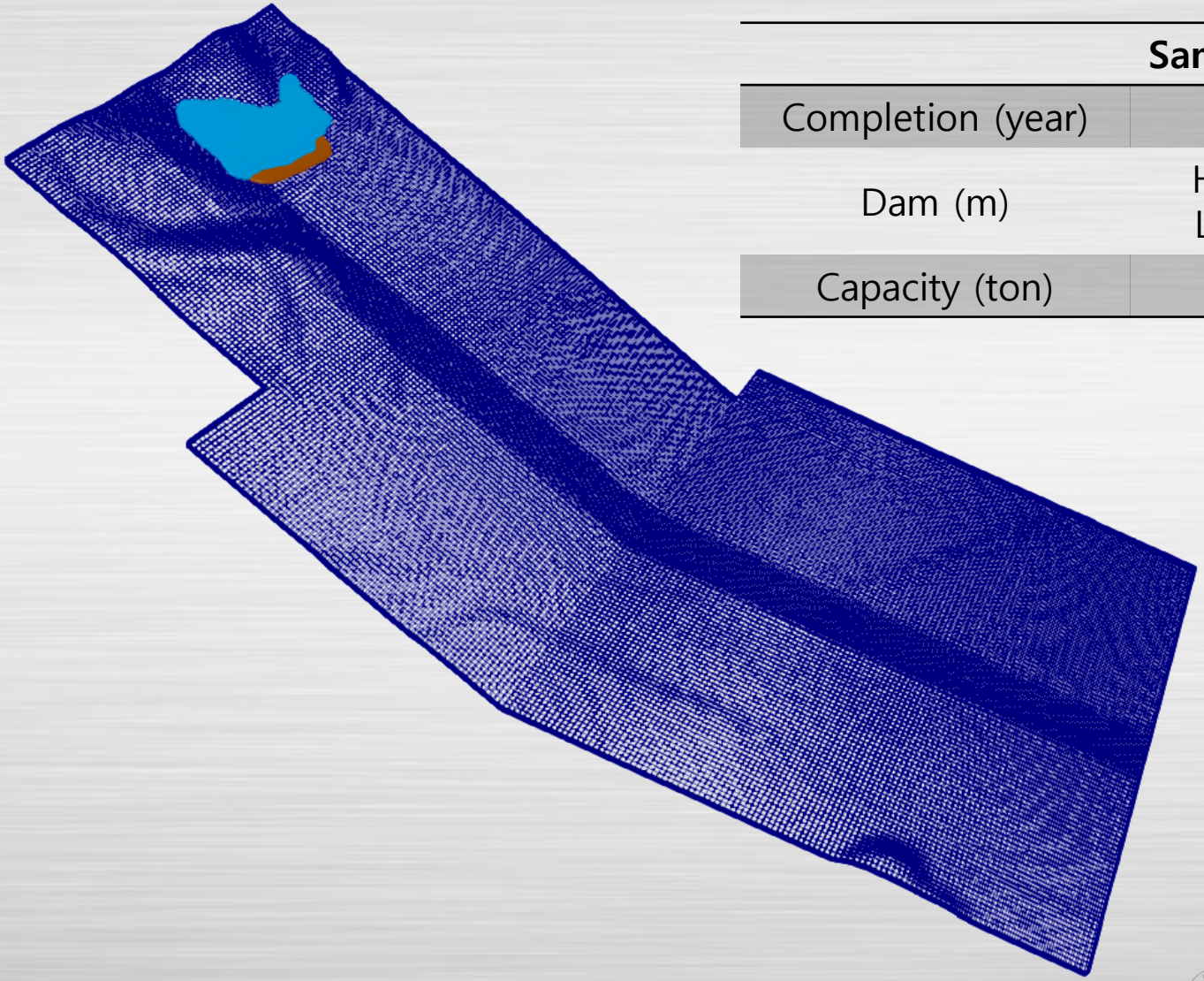


Lee et al(2015)

Estimated damage area : 394,513m^2

* Estimated damage area : Survey and field survey

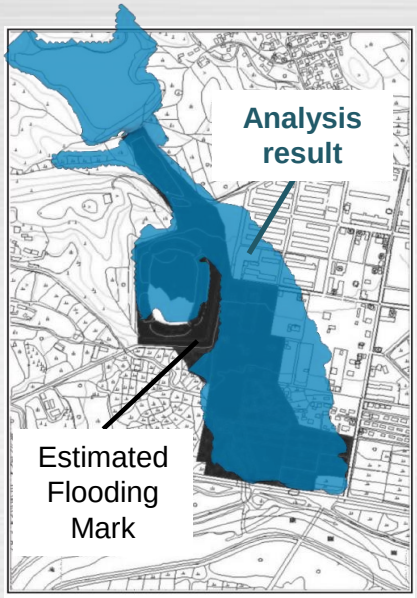
Computer Modeling



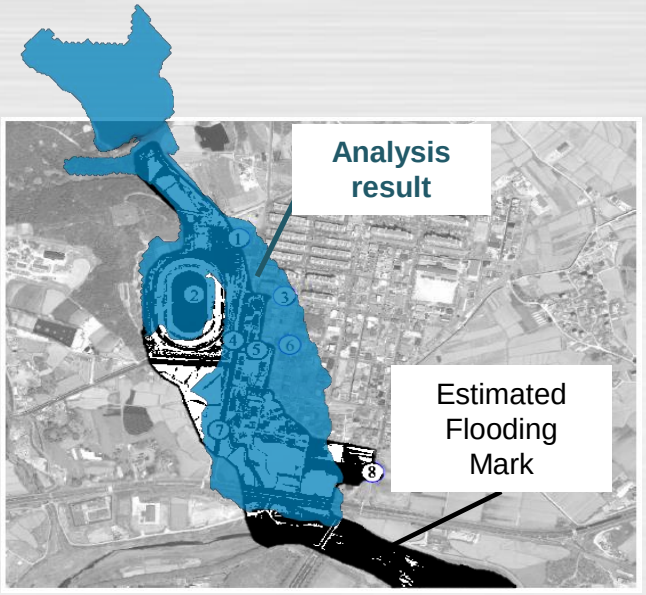
	Sandae resevoir
Completion (year)	1964
Dam (m)	Height 12.2 Length 210
Capacity (ton)	245,000

Analysis result

Comparison of Flooding Map



Go et al(2015)



Lee et al(2015)

		Flooded area(m^2)		
		Estimated	Analysis result	
Previous Research	Go et al(2015)	177,750	196,400	
	Lee et al(2015)	394,513	355,005	River area included
This Research		-	209,860	

Conclusion

- 3D Realization of Collapse 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
- Simulation of Sandae Reservoir Collapse Results in Predicting more Accurate Flooding Range than Existing Methods