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Entrainment effect on impact force of debris flow on check dam by using coupled Lagrangian – Eulerian (CEL) method

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ABSTRACT

The large deformation analysis for debris flows was conducted by using coupled Eulerian- Lagrangian (CEL) technique in ABAQUS. The emphasis was on analyzing the effects of the entrainment process on impact force of debris flows. To consider the entrainment of soil layer, the shear strength of the soil layer changed from the solid state to the fluid state according to the deviatoric plastic strain. As a result, the impact pressure of the debris flows considering the entrainment process was more extensive than the analysis without entrainment. This rigorous FE analysis method can indicate the potential influence of debris flows and estimation of dynamic impact force on check dam. This method could be used to hazard mitigation evaluation and the design of the check dam.

Keywords: debris flows; check dam; large deformation FE analysis; dynamic impact force

1 INTRODUCTION

Debris flows are one of the most hazardous and unpredictable surface processes that result in many losses of lives and property damages. Debris flows can transform from an initially small flow to a massive, hazardous flow by entraining sediment from the channel bed and banks. The entrainment process plays a key role in debris-flow dynamics and should be considered in dynamic debris-flow models (Iverson, 2005; McDougall and Hungr, 2005). Debris flows with a large mass and velocity can apply tremendous impact forces on an obstacle in its flow path. The magnitude of debris-flow impact depends primarily on the velocity, height of debris flows and the sediment. In order to protect humans and infrastructures against debris flows, two different types of debris-flow models, process and impact model, are necessary (Proske at. al., 2011).

In this study, large deformation analysis for debris flows was conducted to analyze the effects of the entrainment process on impact force of debris flows by using coupled Eulerian- Lagrangian (CEL) technique in ABAQUS. As a result, the impact pressure of the debris flows considering the entrainment process was more extensive than the analysis without entrainment. This rigorous FE analysis method can indicate the potential influence of debris flows and estimation of dynamic impact force on check dam. This method could be used to hazard mitigation evaluation and the design of the check dam.

2 METHOD

2.1 Coupled Eulerian and Lagrangian method

The combined Eulerian-Lagrangian (CEL) method, which captures the advantages of the Lagrangian and Eulerian methods, is one of the large deformation analysis methods for problems in geomechanics (Qiu et al., 2011). A significant benefit of the coupled Eulerian-Lagrangian method is that there is no requirement to generate a conforming mesh for the Eulerian region. The movement of the material properties within the Eulerian region can be determined as the volume ratio, the Eulerian volume fraction (EVF) of each element. Each Eulerian element has represented a percentage, which the portion of that element filled with a material. As shown in Fig. 1, when the Eulerian elements filled with a material, EVF is 1, whereas when there is no material in part, EVF is 0.

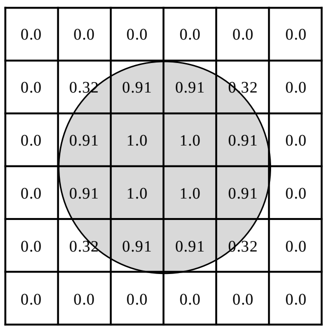

Fig. 1. Eulerian volume fraction (EVF)

2.2 Geometry and boundary condition

The analysis of the debris flows is composed of the soil layer, bedrock, check dam and void area. Lagrangian elements are applied to relatively hard bedrock components and structures. Eulerian elements are applied to the erodible soil layer and the debris flows. A typical 3D coupled Eulerian-Lagrangian (CEL) analysis geometry for the dynamic impact force on check dam is depicted in Fig. 2. The initial debris-flow volume was 3 m^3 (3 m × 1 m × 1 m) and 35 ° in inclination angle, and the transportation area was defined as 10 m in length and 20 ° in inclination angle. The dam was modeled as 1.5 m high, 1 m wide, and 0.5 m thick. The boundary conditions of the check dam are defined only on the bottom, and the displacements in all directions are fixed. The loading condition considered in this analysis was gravity in the z-direction.

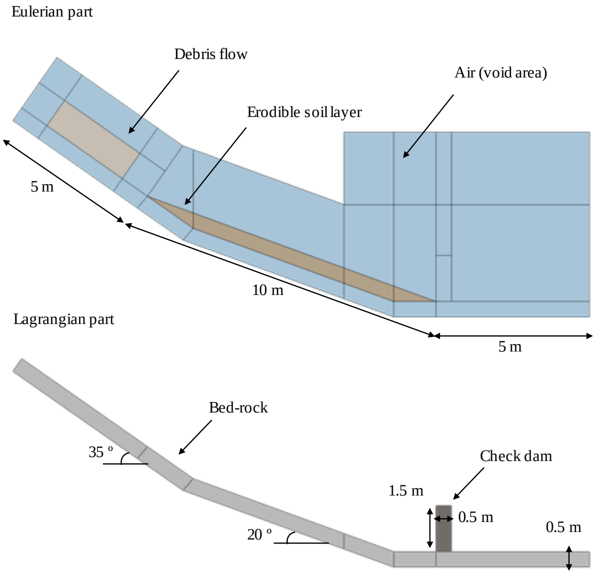

Fig. 2. Idealized 3D model for impact on debris flow barrier

3 VALIDATION

3.1 Entrainment of soil layer

The numerical method for the debris-flow analysis with entrainment was validated through a comparison with a laboratory test that was carried out by Mangeney et al. (2010). As shown in Fig. 3, the test bench was formed with a length of 3 m, and a width of 0.1 m and the slope was designed to be adaptable up to 30 °. The initial volume of the experiment was 0.0028 m^3, and the test was carried out with a different slope (0 to 25.2 °) and erodible bed thickness (0 to 5 mm). To analyze the debris-flow, it was recorded at intervals of ΔT = 0.16sec from T = 0 sec to T = 1.92 sec using a high-speed camera (150-200 frames/sec). In this study, the experiment with an erodible bed thickness of 4.6 mm at an inclination of 22 ° was adopted. It consists of a Lagrangian part, and a Eulerian part with two part is superimposed. The initial volume of debris flows and the erodible bed is modeled using Eulerian element, while flume and run-out pad are treated using Lagrangian element. In this analysis, the only load condition that is gravity acceleration in the z-direction was applied. The boundary conditions were fixed the displacements in the x, y, and z directions on the bottom surface to keep the flume from moving. The mesh of the debris flows was consisted by 8-noded Eulerian brick elements (EC3D8R), and the flume domain was applied to 8-noded Lagrangian brick elements (C3D8R). The properties required for the analysis used the values given in the reference paper (Mangeney et al., 2010).

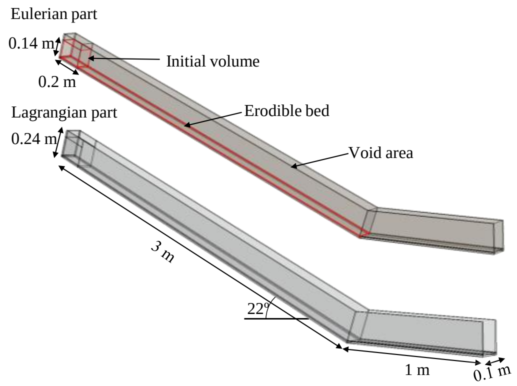

Fig. 3. Geometry used in 3D FE analysis (Mangeney et al., 2010)

Fig.4 shows the shape and thickness of the debris flows according to the step increment (Step = 0, Step = 2, Step = 4). The debris flows were started at the thickness of 0.14 m (Step = 0), and decreases to 0.125 m due to gravity at Step = 2, and flows down to 0.28 m. At Step = 4, it decreases to 0.08 m and flows down to 0.74 m. Debris-flow height compared with the flume test. The simulated results are in good agreement with the laboratory test results that the applied method is appropriate for simulating debris flows with entrainment of the soil layer.

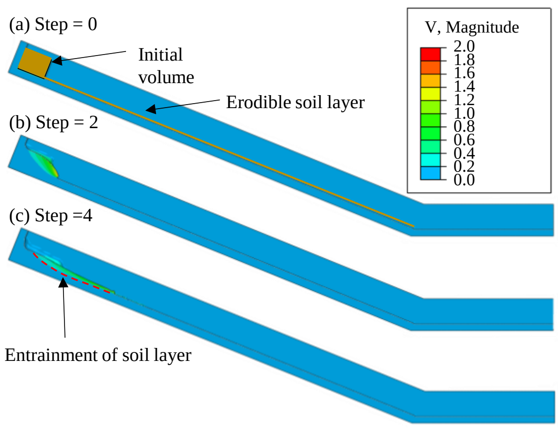

Fig. 4. Analysis result of flow height and velocity.

2.4 Impact force of debris flows

The applicability of the coupled Eulerian-Lagrangian (CEL) method to the analysis of debris flows was verified in comparison with laboratory tests. To verify the proposed method for the debris flows analysis with dynamic impact force, the laboratory tests (Moriguchi et al., 2009) was chosen. The analytical results were compared with the velocity and shape of the debris flows as well as the impact force measured by the load cell. The physical laboratory modeling of debris flows was performed at different slopes and measure the impact force exerted by this material on a fixed rigid wall. The surface of the flume was coated with the same sand to provide surface friction. The flume was designed with a length of 1.8 m and a width of 0.3 m, and the slope was designed to be adjustable from 45° to 65°. In this study, 45° experiment was selected for validation. The geometry of the analysis is depicted in Fig. 5. The Flume and measurement instrument were modeled using Lagrangian elements and the initial volume of debris and are were modeled using Euler elements. The gravity in the z-direction is defined as the only loading condition. Boundary conditions were set on the floor space to fix all displacements in the x, y, and z directions and for the size space to fix only displacements in the x, and y directions. The mesh of the debris flows and flume domain consists of 8-noded Eulerian brick elements (EC3D8R) and 8-noded Lagrangian brick elements (C3D8R), respectively. The constitutive behavior of sand is modeled with an elastic-perfectly plastic model with Mohr-Coulomb failure criterion. The properties required for the analysis used the values given in the reference paper (Moriguchi et al., 2009). In order to the analysis, the necessary properties were estimated based on the proposed property values, and the values required for the analysis were estimated based on the given values.

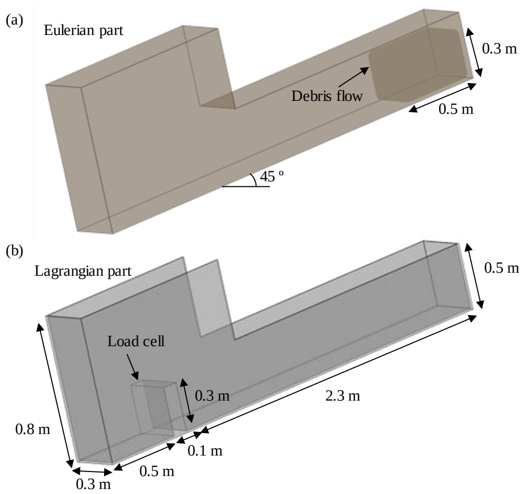

Fig. 5. Geometry used in 3D FE analysis (Moriguchi et al., 2009)

Fig. 6 shows the experimentally and numerically observed free surface configurations on a flume inclined at θ = 45° at different time instants (T = 0.4 sec, T = 1.2 sec). To make the free surface more visible, a red outline was drawn on the surface of the sand at each snapshot. The last two snapshots show the debris flows overtopping the wall. Debris-flow accelerates and elongates while descending the slope. When debris flows reach the load cell, debris flows were deviated upwards, parallel to the wall, with the formation of a bulge, and it subsequently decelerates. The simulated results capture the experimentally observed flow behavior which flows velocity and shape of debris flows. In the CEL analysis, the total impact force is the value of the contact force at the contact surface between the Lagrangian part and Eulerian part. The total impact force was calculated as the sum of the normal forces on the structure.

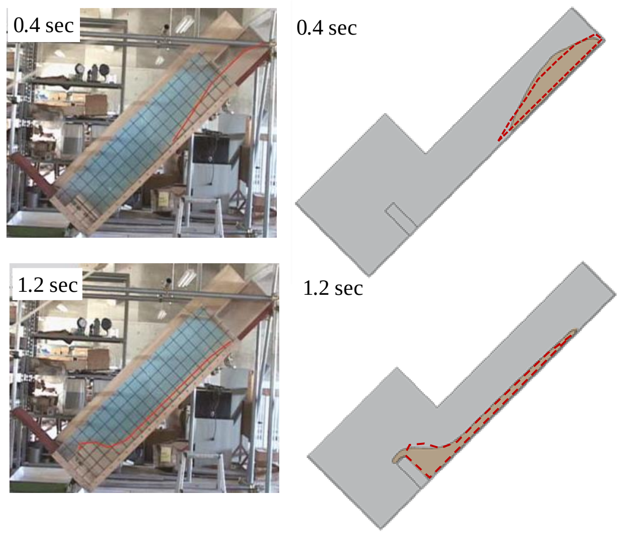

Fig. 6. Results of the height and shape of the debris flows (Moriguchi et al., 2009)

4 NUMERICAL ANALYSIS

Debris flows can get a lot of its destructive power from entrainment along the debris-traversing path (Iverson et al., 2011). However, limited attention has been paid to the influence of impact force of debris flows consideration the erosion and deposition processes. Efforts are needed to include erosion and entrainment processes when simulating debris-flow impact force. In this study, to understand the influence of the entrainment on the impact force, the dynamic impact force with entrainment and without entrainment analyzes were performed. Fig. 7 presents the results of the shape and velocity vector of debris flows in the analysis with entrainment of the soil layer.

In the analysis without entrainment, debris flows were progressively impounded upstream of the check dam after the first contact of the debris flows to the check dam. However, some debris flows over the check dam immediately after the impact in the interpretation taking into account the entrainment.

Fig. 8 shows a comparison of the time history of the impact pressure on check dam with and without entrainment. As a result, the impact force of the debris flows considering the entrainment process was larger than the analysis without entrainment. In the analysis of entrainment, the dynamic impact pressure was appeared by the debris flows, however it increased gradually according to the depth of debris deposition in analysis without entrainment.

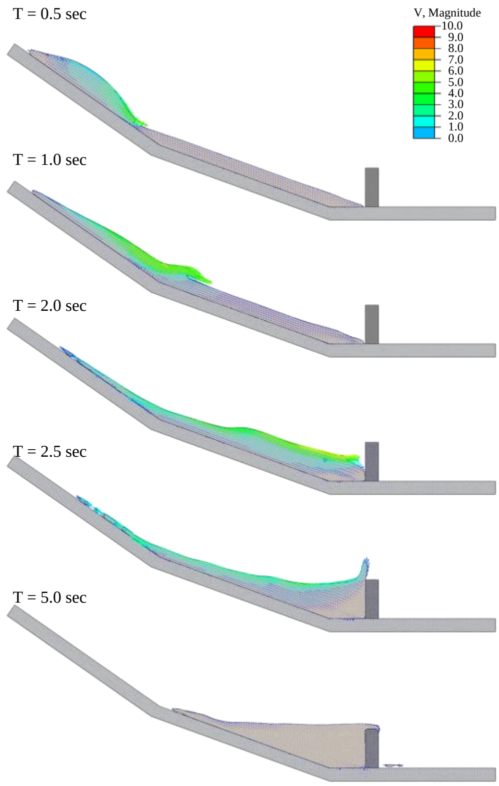

Fig. 7. Velocity vectors for debris flow impact with entrainment

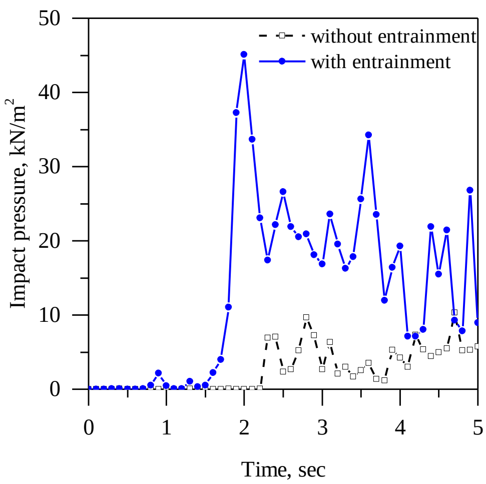

Fig. 8. Comparison of impact pressure with and without entrainment

5 CONCLUSION

In this study, the impact force of debris flows on check dam was analyzed by using Coupled Eulerian-Lagrangian (CEL) take into account the fluid-solid interactions. The results of this investigation are summarized below.

1) The primary objective of this study was analyzed the behavior of debris flows with impact force on check dam using the large deformation FE analysis technique of a coupled Eulerian-Lagrangian (CEL) technique. The analytical method was validated using published data on laboratory experiments.
2) The impact force of the debris flows considering the entrainment process was more extensive than the analysis without entrainment. This rigorous FE analysis method can indicate the potential influence of debris flows and estimation of dynamic impact force on check dam. This method could be used to hazard mitigation evaluation and the design of the check dam.

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