Sustainable Civil Infrastructures

J. James Yang
Wen-Chieh Cheng
Shuying Wang *Editors*

Advanced Tunneling Techniques and Information Modeling of Underground Infrastructure

Proceedings of the 6th GeoChina International Conference on Civil & Transportation Infrastructures: From Engineering to Smart & Green Life Cycle Solutions – Nanchang, China, 2021

SSIGE

Springer

Sustainable Civil Infrastructures

Sustainable Civil Infrastructures (SUCI) is a series of peer-reviewed books and proceedings based on the best studies on emerging research from all fields related to sustainable infrastructures and aiming at improving our well-being and day-to-day lives. The infrastructures we are building today will shape our lives tomorrow. The complex and diverse nature of the impacts due to weather extremes on transportation and civil infrastructures can be seen in our roadways, bridges, and buildings. Extreme summer temperatures, droughts, flash floods, and rising numbers of freeze-thaw cycles pose challenges for civil infrastructure and can endanger public safety. We constantly hear how civil infrastructures need constant attention, preservation, and upgrading. Such improvements and developments would obviously benefit from our desired book series that provide sustainable engineering materials and designs. The economic impact is huge and much research has been conducted worldwide. The future holds many opportunities, not only for researchers in a given country, but also for the worldwide field engineers who apply and implement these technologies. We believe that no approach can succeed if it does not unite the efforts of various engineering disciplines from all over the world under one umbrella to offer a beacon of modern solutions to the global infrastructure. Experts from the various engineering disciplines around the globe will participate in this series, including: Geotechnical, Geological, Geoscience, Petroleum, Structural, Transportation, Bridge, Infrastructure, Energy, Architectural, Chemical and Materials, and other related Engineering disciplines.

SUCI series is now indexed in SCOPUS and EI Compendex.

More information about this series at http://www.springer.com/series/15140

J. James Yang · Wen-Chieh Cheng ·
Shuying Wang
Editors

Advanced Tunneling Techniques and Information Modeling of Underground Infrastructure

Proceedings of the 6th GeoChina International Conference on Civil & Transportation Infrastructures: From Engineering to Smart & Green Life Cycle Solutions – Nanchang, China, 2021

Springer

Editors
J. James Yang
School of Civil Engineering,
College of Engineering
University of Georgia
Athens, GA, USA

Wen-Chieh Cheng
School of Civil Engineering
Xi'an University of Architecture
and Technology
Xi'an, China

Shuying Wang
School of Civil Engineering
Central South University
Changsha, China

ISSN 2366-3405 ISSN 2366-3413 (electronic)
Sustainable Civil Infrastructures
ISBN 978-3-030-79671-6 ISBN 978-3-030-79672-3 (eBook)
https://doi.org/10.1007/978-3-030-79672-3

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Introduction

This volume contains eight papers that were accepted and presented at the GeoChina 2021 International Conference on Civil and Transportation Infrastructures: From Engineering to Smart and Green Life Cycle Solutions in Nanchang, China, September 18–19, 2021. It features novel tunneling technologies and analytical and numerical methods for behavior analysis and modeling of soils and underground infrastructure. A number of important topics are covered, including methodological and pragmatic solutions to critical issues in tunnel engineering (e.g., soil arching and invert heaving), investigations on soil behavior (e.g., penetration resistance of mono-bucket foundations in silty soil and inception of debris avalanches), as well as novel approaches to infrastructure condition survey and inspection based on point cloud data and infrared image analysis. It is anticipated that this collective information will lead to improved safety and resilience in design and construction, and efficiency and sustainability in maintenance and management of underground infrastructure.

Contents

About the Editors

Prof. J. James Yang is an associate professor of Civil Engineering in the College of Engineering at University of Georgia. He received his Ph.D. degree from the University of South Florida. He is a professionally registered transportation engineer with a research interest in sustainable and resilient infrastructure systems, smart mobility systems, statistical and econometric methods, artificial intelligence and machine learning methods and applications. His work has generated several patents and over 40 publications in refereed journals and conference proceedings. He currently sits on the Editorial Board of ASCE Journal of Infrastructure Systems, the TRB AED50 committee: Artificial Intelligence and Advanced Computing Applications, and the Transportation Demand Management Coordinating Committee (TDM-CC) of Atlanta Regional Commission.

Professor Wen-Chieh Cheng is a professor of Geotechnical Engineering in the School of Civil Engineering at Xi'an University of Architecture and Technology. He received his Ph.D. degree from the National Taipei University of Technology. He is a professionally registered civil engineer with a research interest in sustainable and resilient infrastructure systems, soil contamination and remediation strategies, trenchless methods, artificial intelligence and machine learning methods and applications. His work has generated several international patents and over 70 publications in refereed journals and conference proceedings. He currently sits on the Editorial Board of ICE Geotechnical Research journal, and the ISSMGE TC213 committee: Scour and Erosion.

Dr. Shuying Wang is a professor of Tunnel Engineering in School of Civil Engineering, Central South University. He obtained his B.E. and M.S. degrees from Central South University, respectively, in 2005 and 2007 and then earned the Ph.D. degree in Missouri University of Science and Technology (Rolla, USA) in 2011. His research interests include conditioning mechanism and handling technology of special soils, tunneling mechanism and safety control technology. He has been hosting about 30 research projects, one of which is National Natural Science Foundation-Outstanding Youth Foundation. So far, more than 70 papers have been published, and 14 patents have been authorized. Additionally, he has gotten one monograph and one textbook pressed in Springer. He won the second prize of science and technology progress of Ministry of Education in 2019 (in the first place) and that of Hunan Province in 2017 (in the third place). He serves as an editorial board member for three journals such as Journal of Testing and Evaluation (ASTM), Chinese Journal of Highway, etc.

Inception of Debris Avalanches: A Material Point Method Modelling

Sabatino Cuomo[1(✉)], Angela Di Perna[1], and Mario Martinelli[2,3]

[1] University of Salerno, Salerno, Italy
scuomo@unisa.it
[2] Deltares, Delft, Netherlands
[3] TU Delft, Delft, Netherlands

Abstract. Rainfall-induced landslides of the flow type in granular soils are among the most complex natural hazards due to the variety of mechanisms which regulate the failure and propagation stages. Among these, debris avalanches are characterised by distinct mechanisms which control the lateral spreading and the increase in soil volume involved during the propagation. Two different stages can be individuated for debris avalanches, i.e. the failure stage and the avalanche formation stage: the former includes all the triggering mechanisms which cause the soil to fail; the latter is associated to the increase of the unstable volume. Regarding these issues, in the literature, either field evidence or qualitative interpretations can be found while few experimental laboratory tests and rare examples of geomechanical modelling are available for technical and/or scientific purposes.

In this paper a contribution is provided about the advanced numerical modelling of the inception of such hazardous debris avalanches. Particularly, the case of the impact of a failed soil mass on stable deposits is considered. This means that a small translational slide occurs; the failed mass causes the soil liquefaction of further material by impact loading; the landslide volume increases inside triangular-shaped areas during the so-called "avalanche formation", and also soil erosion along the landslide propagation path plays an important role.

To this aim, an innovative numerical technique known as the Material Point Method (MPM) is used. It can be considered as a modification of the well-known Finite Element Method (FEM) particularly suited for large deformations. The continuum body is schematized by a set of Lagrangian points, called Material Points (MPs). Large deformations are modelled by MPs moving through a background mesh, which also covers the domain where the material is expected to move. The MPs carry all physical properties of the continuum such as stress, strain, density, momentum, material parameters and other state parameters, whereas the background mesh is used to solve the governing equations without storing any permanent information. Such advanced approach allows combining a hydro-mechanical coupled approach, any of the well-known soil constitutive models proposed over the years in soil mechanics and a large-displacement formulation.

The numerical analyses are performed adopting 2D geometrical configurations taken from field evidences and previous researches. Triangular 3-noded computational meshes are used, characterized by elements of about 1 m. The interaction between the impacting mass, and then of the propagating flow with the in-situ stable soil is examined, providing important insights about the behaviour

J. J. Yang et al. (Eds.): GeoChina 2021, SUCI, pp. 1–15, 2021.
https://doi.org/10.1007/978-3-030-79672-3_1

of such type of landslide. The results achieved so far are encouraging and show that MPM can properly simulate the inception of debris avalanches and even their complex mechanisms during the impact and the interaction with in-situ stable zones.

1 Introduction

Flow-type landslides are among the most complex natural hazards due to their high velocities and long run-out distances and also to the variety of mechanisms that occur within failure and post-failure stages (Pastor et al. 2009; Cascini et al. 2012; Cuomo 2020). In the specific, the so-called "debris avalanches" still pose significant open issues in the scientific debate, since a consistent mathematical framework for their analysis has not yet been formulated.

According to the most recent landslide classification (Hungr et al. 2014), the term "debris avalanche" states for "very rapid to extremely rapid shallow flow of partially or fully saturated debris on a steep slope, without confinement in an established channel". They typically occur in open slopes, i.e. shallow soil deposits with almost constant depths and slope angles generally between 30° and 45°. In particular, debris avalanches start with small involved volumes (failure stage) and then turn into larger landslides because of the increasing in mobilized volume through further failures or eventual soil entrainment and resulting as a triangular-shaped area (post-failure stage).

Additional to that, soil unsaturated condition may be a key factor, in the failure and post-failure stages. Before failure, the additional strength related to matric suction is fundamental for the equilibrium of granular soil slopes steeper that the effective friction angle. During the failure stage of rainfall-induced landslides, the soil suction gradually reduces due to rain infiltration and peculiar mechanical responses can even occur such as the capillary collapse (strong reduction of soil volume related to wetting). But also during the propagation stage soil suction may evolve towards higher or smaller values depending on the amount of deformation in the landslide body. Thus, it would be desirable to have a comprehensive hydro-mechanical-coupled and large-displacement-based approach to include and accurately analyse all of these issues.

Referring to failure and post-failure stages, four different zones can be distinguished (Fig. 1). Zone 1 corresponds to small failures that occur at natural or anthropogenic discontinuities of soil deposits (respectively, bedrock outcrops and cut slopes). Zone 2 is the impact zone of the previously mentioned failed masses that usually corresponds to water supplies from bedrock (either karst spring or water runoff at bedrock outcrops); if zone 1 is absent, zone 2 is the source area of small landslides triggered by water supplies from bedrock. Zone 3 corresponds to distinct mechanisms: thrust of the failed mass upon the downslope stable material and/or soil entrainment due to the propagating mass. Zone 4 exclusively corresponds to soil entrainment. It is worth noting that while zones 1 and 2 are few tens of metres large, the width of zones 3 and 4 is not known a priori and its forecasting is a challenging task.

Generally, for analysing the triggering of a landslide, classical approaches like Limit Equilibrium Methods (LEMs) are often employed, which completely neglect the soil deformations and rely only on equilibrium equations under simplified hypotheses. Alternatively, or in conjunction to that, stress-strain analyses through Finite Element Methods

(FEMs) have been also performed, considering the soil deformations generally "small". This simplification may be a reasonable hypothesis when the pre-failure and the failure are the only issues of the analysis. In addition, the hydro-mechanical coupling between the solid skeleton and the pore water pressure can be rigorously taken into account.

On the other hand, the propagation stage of such kind of landslides has been mostly analysed in terms of soil displacements, but not so much in terms of hydromechanical coupling during soil evolution. The simulation of the propagation stage during slope instability was managed through several approaches, such as discrete element method (Cuomo et al. 2019; Zhao et al. 2019) or Lagrangian particle-based methods such as SPH, PFEM, FEMLIP, MPM (Cuomo et al. 2013, 2015; Ceccato et al. 2018a; Cuomo 2020; Yuan et al. 2020).

In this paper, an effort is done to provide a conceptual and computational tool useful to perform different types of analysis in order to capture the essential aspects of complex hydro-mechanical behaviour during the inception and evolution of a debris avalanche following the impact of an unstable mass. To this aim, MPM proves to be a powerful method, able in simulating the complex mechanics of landslide motion during the failure, propagation and deposition stages.

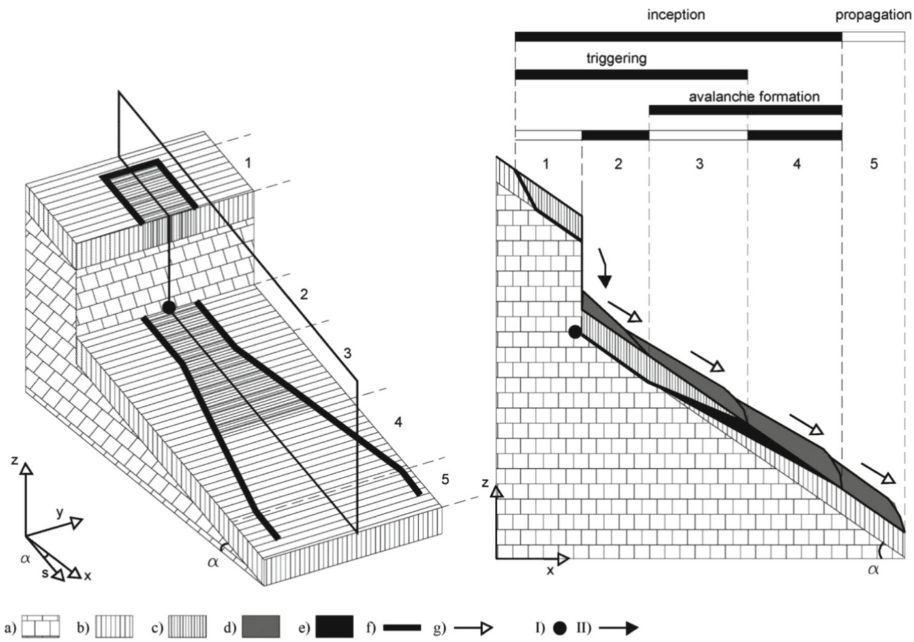

Fig. 1. A reference scheme for the inception and propagation of a debris avalanche. General features: a) bedrock, b) stable soil deposit, c) failed soil, d) propagating failed mass, e) entrained material, f) boundary of debris avalanche and g) propagation pattern. Triggering factors: I) spring from bedrock, II) impact loading. *Zone 1–2* triggering; *zone 3* thrust of failed material and/or soil entrainment; *zone 4* soil entrainment, zone 5 propagation (Cascini et al. 2012).