

See discussions, stats, and author profiles for this publication at: <https://www.researchgate.net/publication/383661404>

Slope failure cause evaluation based on earthworks management and meteorological conditions analyses

Conference Paper · August 2024

DOI: 10.1201/9781003431749-346

CITATIONS

0

READS

156

6 authors, including:



Nguyen Quang Tuan

Thuyloi University

27 PUBLICATIONS 18 CITATIONS

[SEE PROFILE](#)



Duc Bui Van

Hanoi University of Mining and Geology

69 PUBLICATIONS 1,011 CITATIONS

[SEE PROFILE](#)



Ngoc Anh Do

Hanoi University of Mining and Geology

69 PUBLICATIONS 1,603 CITATIONS

[SEE PROFILE](#)



Piotr Osinski

Warsaw University of Life Sciences

85 PUBLICATIONS 1,207 CITATIONS

[SEE PROFILE](#)

Slope failure cause evaluation based on earthworks management and meteorological conditions analyses

Évaluation de la cause de la défaillance du talus, basée sur l'analyse de la gestion des travaux de terrassement et des conditions météorologiques.

T.Q. Nguyen

Thuyloi University, Hanoi, Vietnam

D.B. Van, M.V. Nguyen, N.A. Do

Hanoi University of Mining and Geology, Hanoi, Vietnam

P. Osinski*, E. Koda

Institute of Civil Engineering, Warsaw University of Life Sciences - SGGW, Warsaw, Poland

**piotr_osinski@sggw.edu.pl*

ABSTRACT: Rainfall-triggered slope failures are a well-known cause of disasters. To increase the stability of slopes a retaining wall is often proposed. However, associated earthworks could bring the great danger of a landslide during the construction process, if not properly managed. The paper aims to investigate the collapse cause of residential buildings located at the edge of the slope in the northwest part of Vietnam, where engineering works were performed to prevent failure due to undercutting soil erosion. During the retaining wall construction works, significant vibrations and additional dynamic loads could have affected the building foundations' bearing capacity, leading to structural failure. Another cause is associated with heavy precipitation recorded at the site just after the excavation works down the slope. The paper consists of analyses allowing simulation of possible scenarios, including the effect of changing saturation conditions using the meteorological data. The analyses concerned slope stability improvement to secure the remaining infrastructure.

RÉSUMÉ: Les glissements de terrain déclenchés par les précipitations sont une cause bien connue de catastrophes liées aux structures. Pour accroître la stabilité, la construction d'un mur de soutènement est souvent proposée. Cependant, de tels travaux peuvent également entraîner un danger élevé de glissement de terrain pendant la construction s'ils ne sont pas gérés correctement. L'objectif de l'article est d'investiguer la cause de l'effondrement des bâtiments résidentiels situés en bordure du talus dans le nord-ouest du Vietnam, où des travaux d'ingénierie ont été effectués pour prévenir les défaillances dues à l'érosion des sols causée par le sous-excavation. Pendant les travaux de construction du mur de soutènement, des vibrations importantes et des charges dynamiques supplémentaires auraient pu affecter la capacité portante des fondations des bâtiments, entraînant une défaillance structurelle. Une autre cause est liée aux fortes précipitations enregistrées sur le site juste avant le début des travaux d'excavation en descente du talus. L'article comprend des analyses permettant de simuler des scénarios possibles, y compris l'effet des conditions de saturation changeantes à l'aide des données météorologiques. Les analyses ont porté sur l'amélioration de la stabilité du talus afin de sécuriser les infrastructures restantes.

Keywords: Slope stability; rainstorm event; infrastructure failure; retaining wall.

1 INTRODUCTION

Slope stability issues are a common safety concern when it comes to development plans in urban areas. Landslides can occur due to natural processes and poor management of developing sites. The natural process like changing climate conditions, are very challenging to control. When it comes to human factor-triggered landslides most of the failures could be easily avoided by fully understanding the danger caused by the construction works and management of developing sites. The present study analyses triggering factors of

the collapse of buildings located by the edge of the natural slope. The collapse is recognised to be associated with extreme precipitation events recorded at the site and poor drainage conditions after the retaining wall construction works.

Retaining walls are primarily designed to improve the structure stability but can also eliminate the soil erosion effect on the river banks or slopes located by the waterways, undercutting the slope at its toe. When considering the construction of the retaining wall in areas of high-risk failure due to the presence of associated infrastructure, the method of reinforcement

installation is crucial (Look, 2022). There are a number of case studies researching rainfall-triggered landslides (Lacroix et al, 2020; Maturidi et al, 2021) or slope failures due to poor execution of earthworks during the installation of reinforcements. Engineering practice shows that one of the most common causes of slope failures is the decrease of soil shear strength due to the development of groundwater pressure at the potential slip surfaces (Filho and Fernandes, 2019). Long-lasting precipitation is affecting dipper parts of a slope profile resulting in severe collapses (Patuti et al, 2017; Alsubal et al, 2019). The present paper aims to investigate the real cause of slope failure in the northwest part of Vietnam. The sequence of events recorded at the site, both natural and manmade, resulted in severe damage to the surrounding infrastructure, forcing the residents to evacuate. The authors tried to reconstruct the process by collecting available data and investigating mechanisms that could have caused the failure of the slope and the infrastructure.

2 STUDY SITE DESCRIPTION

The case study site is located in a mountainous district in the centre of Dien Bien province, in the northwest part of Vietnam (Figure 1). It is divided into two landform zones where the terrain elevation ranges from 350-1000 m a.s.l. The terrain is morphologically complex with a number of valleys and rivers crossing the entire region, where during the wet season the meandering streams are cutting the mountain toes. What is important for the case study is the presentation of the local climate condition that has a major effect on the working conditions of the infrastructure and causes of natural hazards. The conditions are typical for tropical monsoon climate. The annual rainfall ranges from 1,600 to 2,400 mm.



Figure 1. Location of study area.

The case study concerns a natural slope with extensive infrastructure developed at the top edge. The infrastructure development started with the construction of a local road near the edge and the design of the drainage system redirecting the runoff down the 25m high slope. Following the road construction number of storey buildings were constructed in the section between the road and the slope's edge. At the toe of the slope, there is a natural stream passing with the flow changing depending on the rainfall volume. In recent years, the local community's major awareness has been focused on the erosion effect due to the stream continuously cutting the toe of the slope. Thus, a retaining wall was constructed to control the water erosion and improve the slope's stability. After the works were accomplished significant rainfall events took place. The finger pipe drainage was installed at the back of the wall. A few weeks later the residents reported the first building cracking, which continued to develop until the next severe rainfall event that was followed by the slope failure and a collapse of buildings located at the study site. Figure 2 presents graphically the sequence of events leading to a final slope failure. The authors of the present paper aim to investigate events and the processes contributing to the failure occurrence. Based on the data collected from the site investigation report, meteorological report and the information gathered during the site visits, the analytical study was performed to reflect the in-situ conditions.

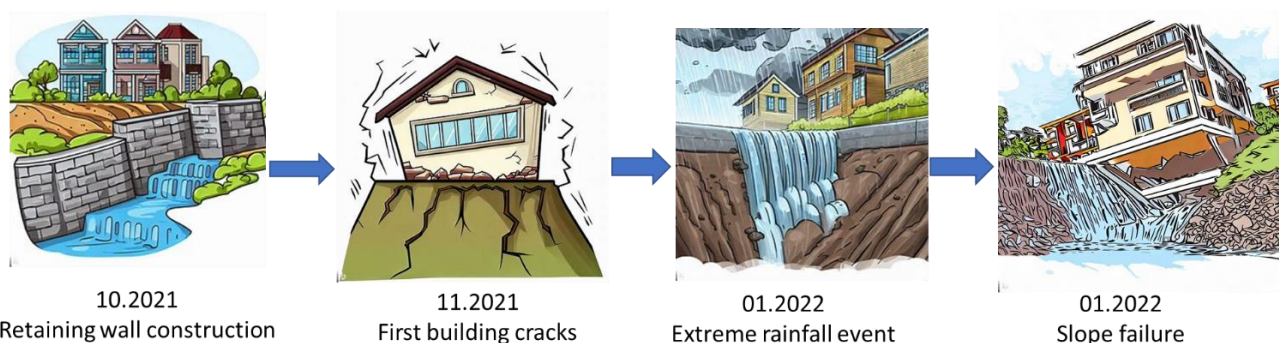


Figure 2. Graphical presentation of the sequence of events leading to a structural failure of residential buildings.

3 GEOTECHNICAL CONDITION

For analyses of the conditions at the study site, a geotechnical investigation was performed. During the site investigation, 11 core samples were collected and transported to the laboratory where physical and mechanical parameters were determined using triaxial tests. There were 4 main geotechnical layers determined, with the groundwater table investigated at 2,5m depth. The experimental results of physico-mechanical parameters are presented in Table 1.

Table 1. Physico-mechanical properties of soil layers.

Parameter	Soil type			
	Fill	Shale *	Shale **	Sandstone **
w (%)	23.9	28.2		
γ (g/cm ³)	1.96	1.90	2.2	2.50
e (%)	0.69	0.8		
Ip (%)	16.2	15.7		
c' (MPa)	0.0167	0.174	0.09	0.18
ϕ' (°)	17	20	32	46

*highly weathered; **moderately weathered

Since the rainfall events in the study were concerned with having a major effect on the failure, the precipitation data were also analysed. To allow further understanding of the failure cause the rainfall data was collected from the nearby monitoring station. Important for the study is the accumulative rainfall of 2000 mm recorded on 10.2021. Another crucial note for the study is that the finger pie drainage behind the retaining wall was found to be clogged during the site investigation.

4 RESULTS AND DISCUSSION

The authors attempted first to reflect the sequence of events by analysing all the circumstances at the site starting with matching the recorded rainfall data with the time of constructing the retaining wall, through observed cracks on the buildings and the time of the final failure of the slope. The graph presented in Figure 3, shows the chronologic sequence of events to give a better understanding of all the possible causes of the final failure of the slope, which eventually resulted in severe damage to the residential buildings. In late 2021, due to the alarming technical condition of the slope, the local authorities decided to support the toe by constructing the retaining wall, in the form of a concrete gravity wall, preventing potential failure. The excavation works that took place on 7-20.10.2021 caused heavy ground vibrations that were reported by the local citizens occupying the buildings located at the top of the slope. Soon after the retaining wall works were completed a significant rainfall event was recorded, reaching 30 mm on 22.10.2021. It is worth noting that the accumulation rainfall recorded for October is 2000 mm. A week later, the first cracks developing in the buildings were observed. It was only 2 months later, on 16.01.2022 when more damages to the building were reported and the slope failed after the rainfall event that reached nearly 45 mm in a single day. Through the analytical approach and detailed investigation of events, it is assumed that two major factors triggering the slope failure were the retaining wall earthworks and poor drainage conditions during the torrential precipitation.

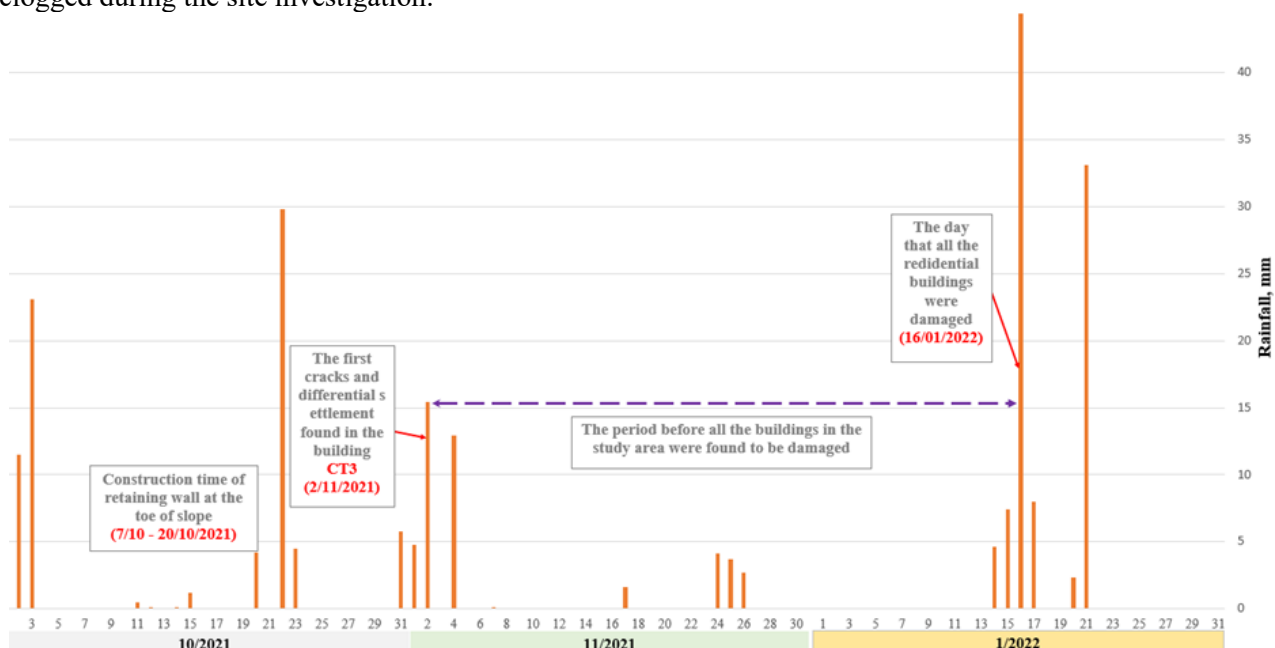


Figure 3. The sequence of events leading to a final failure with referencing rainfall data recorded in the study area.

During the earthworks, the dynamic loads loosened the soil material at the building foundation. The following rainfall could then easily penetrate the soil profile causing the decrease of the soil's mechanical parameters due to build-up of effective stress, also caused by poor drainage conditions. Based on geotechnical investigation data and rainfall volume the computations of geotechnical safety were performed to determine the failure mechanism and to reflect the sequence of the events. Based on the analyses the restoration works and computations of geotechnical safety were performed. The slope stability analyses were performed using the finite element method for the parameters obtained from the site investigation. The geotechnical model used for further analyses was based on the Mohr-Coulomb

soil model, and the factor of safety was computed based on the shear strength reduction method. There were different scenarios for the analyses applied, depending on the changing groundwater level due to rainfall and infiltration. To ensure safety the entire slope was re-engineered and reinforcement such as MSE and gabion wall was proposed. The system allowed for minimising the excavation and earthworks' impact on the remaining infrastructure so as not to cause any more damage. Finding the optimum solution, the deformations and the factor of safety were computed as presented in Figure 4. The obtained factor of safety was $1.34 > [FS]=1.25$ and maximum horizontal displacement did not exceed $4.25 \text{ cm} < [\delta]=H/200 = 7.5 \text{ cm}$, where H is the total height of the wall.

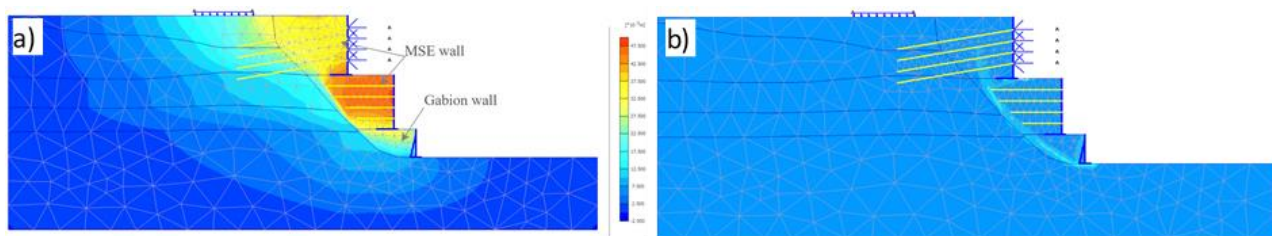


Figure 4. Computations of geotechnical safety a) displacements, b) FS and slip surface determination.

5 CONCLUSIONS

The study's objective was to investigate the on-site conditions and imitate the events that may have led to the residential building damage and eventually the slope failure. The site investigation data, meteorological monitoring reports, drainage conditions and the examination of earthworks during the construction of the retaining wall allowed comprehensive examinations of events that contributed to the slope's failure. Based on all the gathered information a reclamation plan was implemented and solutions for improving the geotechnical safety were proposed, by computing the factor of safety and total deformations of failed and then newly engineered slopes. The lesson learned from the case study is that the earthwork aiming at improving safety, in particular circumstances, when dealing with severe weather events could have the opposite, even damaging effect.

REFERENCES

- Alsubal, S., Sapari, N., Harahap, S. and Al-Bared, M., (2019). A review on mechanism of rainwater in triggering landslide. In *IOP Conference Series: Materials Science and Engineering*. IOP, 513(1): 012009. <https://doi.org/10.1088/1757-899X/513/1/012009>.
- Filho, O. and Fernandes, A. (2019). Landslide analysis of unsaturated soil slopes based on rainfall and matric suction data. *Bulletin of Engineering Geology and the Environment*, 78: 4167-4185. <https://doi.org/10.1007/s10064-018-1392-5>.
- Lacroix, P., Handwerker, L. and Bièvre, G. (2020). Life and death of slow-moving landslides. *Nature Reviews Earth & Environment*, 1(8): 404-419. <https://doi.org/10.1038/s43017-020-0072-8>.
- Look, G. (2022). *Earthworks: Theory to Practice-Design and Construction*. CRC Press. London. UK. <https://doi.org/10.1201/9781003215486>.
- Maturidi, M., Kasim, N., Taib, A. and Azahar, N. (2021). Rainfall-induced landslide thresholds development by considering different rainfall parameters: A Review. *Journal of Ecological Engineering*, 22(10): 85-97. <https://doi.org/10.12911/22998993/142183>.
- Patuti, M., Rifa'i, A. and Suryolelono, B. (2017). Mechanism and characteristics of the landslides in Bone Bolango regency, Gorontalo province, Indonesia. *Geomate Journal*, 12(29): 1-8. <https://doi.org/10.21660/2017.29.79901>.

Alsubal, S., Sapari, N., Harahap, S. and Al-Bared, M., (2019). A review on mechanism of rainwater in