京都大学	博士（工学）	氏名	Wongchana Pongsakorn
論文題目	Mitigation of dip slope collapse due to groundwater infiltration using counterweight fill and slope stability analysis considering lateral confinement （押え盛土を用いた地下水浸透による斜面崩壊の軽減と側方拘束を考慮した安定性解析）		

A slope lying on bedding, often referred to as a dip slope, is a geological formation where the slope surface parallels or closely follows the orientation of underlying sedimentary rock layers or bedding planes. Dip slopes have a potential for landslides, as evidenced by past incidents where landslides have caused damage to infrastructure and posed risks to human safety. This thesis focuses on the stability analysis of dip slopes under varying conditions, with an emphasis on groundwater infiltration and seismic activity. The primary objective is to develop theoretical models and conduct physical experiments to understand the failure mechanisms and improve the assessment of dip slope stability.

A physical model of a dip slope was designed and utilized to investigate failure mechanisms under controlled conditions. Experiments employed both 1g and centrifuge setups to simulate realistic scenarios and evaluate the impact of different factors on slope stability. The reverse toe angle emerged as a critical factor influencing failure modes, with distinct behaviors such as toe sliding and thrust failure identified and analyzed using Particle Image Velocimetry (PIV) techniques. Additionally, a novel minimum coefficient of variation method was developed to analyze PIV results and detect slip line formations. The centrifugal model was newly designed to incorporate the effect of groundwater infiltration.

Theoretical analyses were developed to complement experimental findings, focusing on assessing dip slope stability under groundwater infiltration. Analysis of dip slope stability was enhanced through considerations of lateral confinement, transitioning from 2 dimensional to 3-dimensional analyses. Results indicated a strong correlation between dip slope stability analyses with lateral confinement and experimental outcomes.

Furthermore, counterweight fill was investigated as an effective measure to mitigate slope instability. Theoretical predictions and experimental observations affirmed that counterweight fill shifts failure modes from toe sliding to thrust failure, thereby enhancing slope stability across varied conditions. Moreover, dip slope stability analysis with lateral confinement was utilized to assess failure modes post-counterweight fill.

Chapter 1 introduces the study, outlining the background, challenges, and in Chapter 2, through comprehensive literature reviews on dip slope, the scope of this study is clarified: Study the reverse toe effect on failure mechanisms of dip slope by physical modelling; Development of PIV analysis with statistical approach to evaluate dip slope failure mechanisms Investigate the effect of groundwater infiltration on dip slopes by centrifugal modelling; Explore counterweight mitigation for dip slope stabilization by centrifugal modelling; Study effect of dynamic loading on dip slope by centrifugal modelling; Development and validation of slope stability analysis formula.

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Chapter 3 details the methodology used to achieve the research objectives. An introduction to the 1g and centrifuge experiments is introduced, followed by a detailed description of the model apparatus and instrumentation used in the centrifuge tests. The geotechnical properties of the sand are thoroughly detailed, along with the sand preparation process. Two advanced techniques for measuring earth pressures and sand deformations are then introduced.

In Chapter 4, a total of 12 tests were conducted under 1g conditions to investigate passive thrust near the slope toe in laterally confined slopes on an inclined bedding plane. Additionally, the failure mechanism related to a reverse toe angle was observed in these experiments. PIV analysis with statistical approaches was applied to analyze the failure mode. Additionally, a newly developed minimum coefficient of variation method was utilized to detect slip lines and determine the time of slope failure. Due to the failure mechanism of dip slopes investigated in Chapter 4, the study will continue to explore the effect of groundwater infiltration on dip slope stability using centrifugal model.

In Chapter 5, six centrifuge tests were carried out to study slope failure subjected to groundwater infiltration on an impermeable bedding plane. A surcharge load cart acted as a moving boundary, triggering the loading in these 24 experiments. Moreover, theoretical calculations of slope stability are provided and compared with the experimental results.

In Chapter 6, five centrifuge tests focused on counterweight mitigation for dip slope failure due to groundwater infiltration on an impermeable bedding plane. Furthermore, theoretical calculations of slope stability with counterweight fill are provided to analyze stability changes subjected to counterweight fill.

In Chapter 7, the behavior of slopes on permeable bedding planes with lateral confinements and toe support was examined through six centrifuge tests, which included two dip slopes without countermeasures and four with countermeasures.

In Chapter 8, one centrifuge test investigated the effect of seismic loading on dip slopes. One test applied four seismic waves to determine the impact of seismic loading on slope failure. In this chapter, a combination of pseudo-static and dip slope stability analysis was performed to compare with experimental results.

The final chapter provides the conclusion of this dissertation and outlines future work.

This thesis advances the understanding of dip slope stability through integrated theoretical analyses and physical modeling. The insights gained contribute to mitigating risks associated with dip slope landslides, thereby supporting more informed geotechnical engineering practices.

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本論文は、斜面崩壊を起こしやすい流れ盤斜面を対象とし、地下水の浸透と地震外力に重点を置き、理論モデルの開発と模型実験を行うことで破壊メカニズムを理解し、従来の斜面安定解析法を改良した精緻な流れ盤傾斜斜面の安定性評価手法を提案するものであり、得られた主な成果は次のとおりである。

１．重力場および遠心場における流れ盤斜面の模型実験で斜面崩壊シナリオを再現し、斜面の安定性に及ぼす様々な要因の影響を評価した結果、法先すべりおよびスラスト破壊という異なる破壊モードが現れることを示すとともに、逆法尻角が破壊モードの分岐に影響を及ぼす重要な要因であることを明らかにした。
２．粒子画像流速測定法（PIV）を用いて定量化した斜面の速度場を解析し、斜面の崩壊面であるスリップラインの形成を検出するための新しい最小変動係数法を開発した。一般に崩壊面はせん断ひずみの集中度から定性的に決定されるが、この研究で開発した手法により、客観的かつ定量的な崩壊面の検出を可能とした。
３．実験結果を補完するために、地下水浸透下での流れ盤斜面の安定性評価に焦点を当てた理論解析を開発した。流れ盤斜面の安定性に関する解析は、斜面側方の縦断方向の拘束を考慮することによって、従来の２次元解析から３次元解析へと拡張した。その結果、斜面側方の縦断方向の拘束を考慮することで、解析結果は実験結果を精度良く表現可能であることが示された。
４．流れ盤斜面の不安定性を緩和する効果的な対策として押え盛土を提案し、理論予測と実験結果から、押え盛土は破壊モードを法先すべりからスラスト破壊に移行させ、斜面の安定性を向上させることを示した。

以上のように、本論文は降雨時や地震時において土砂災害の頻繁に発生する流れ盤斜面の崩壊メカニズムを模型実験により明らかにするとともに、従来２次元条件下で実施されてきた斜面安定理論解析を斜面側方の縦断方向の拘束を考慮して３次元に拡張し、その効果を模型実験で検証することによって、新たな信頼性の高い斜面安定解析を実現したものであり、学術上、実際上寄与するところが少なくない。よって、本論文は博士（工学）の学位論文として価値あるものと認める。また、令和６年７月１９日、論文内容とそれに関連した事項について試問を行って、申請者が博士後期課程学位取得基準を満たしていることを確認し、合格と認めた。なお、本論文は、京都大学学位規程第１４条第２項に該当するものと判断し、公表に際しては、令和８年９月２４日までの間当該論文の全文に代えてその内容を要約したものとすることを認める。

要旨公開可能日：令和６年１２月２０日以降