長期滞在型共同研究（ 課題番号：28L-01 ）

課題名：Instability of Slopes Modified by Engineered Fill Materials due to Long-period Earthquake Ground Motion: A Comparison Study of New Zealand and Japan
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滞在期間：平成 28 年 11 月 5 日 ～ 平成 28 年 12 月 11 日
滞在場所： Research Center on Landslides, DPRI, Kyoto University
共同研究参加者数： 7 名 (所外 3 名，所内 4 名)
・大学院生の参加状況： 1 名（博士 1 名）（内数）
・大学院生の参加形態 [実験およびデータ解析の補助，学術議論の参加]

研究及び教育への波及効果について

- 地震や豪雨時におけるニュージーランド Wellington 市内の谷埋め盛土の安定性および不安定化した後の崩土の運動挙動について検討した．これらの研究成果は，Wellington 市内の谷埋め盛土だけではなく，同じ地質材料を用いた他地域の谷埋め盛土における斜面防災対策にも貢献できると思われる．
- 1 名の大学院生および 1 人の外国人共同研究者が，実験の実施およびデータの解析に参加し，活発な議論を行った．これらの活動に参加し，異なる国からの研究者との交流ができて，人材育成の面で大きな波及効果が得られた．

研究報告

(1)目的・趣旨

A significant number of slopes in the major cities of both New Zealand and Japan have been modified with engineered fill materials. Whilst many of these cities are seismically active, very little information exists on how such fill slopes behave in response to ground shaking and specifically how susceptible they may be to earthquake-induced failure.

We assessed the response of typical fill slopes materials collected from a landslide site in central Wellington, New Zealand by performing dynamic shear tests using the dynamic ring shear apparatus at DPRI, Kyoto University. During the testing particle size and density of the fill materials was varied to determine how these key factors may influence fill slope failure susceptibility. The research provides new knowledge to improve the resilience of both Japan's and New Zealand's infrastructure through better knowledge of how fill-slope materials are affected in both the short and long term by episodic earthquake shaking which will aid in the development of robust remediation approaches.

(2)研究経過の概要

2.1 Introduction

Engineered fill-slopes are a common form of earth surface modification across many urban centres, and are created largely in response to the growing demands on development. The Wellington region is known to be particularly susceptible to landsliding due to its topography, climate and seismic activity. Records indicate about 400 documented slope failures on Wellington City Councils road network per year, the majority of which occur in engineered cut or fill slopes.

The potential hazard fill-slopes may pose has been highlighted by a number of failure events over the past 10 years. Despite such events, limited research has been undertaken to understand the failure mechanisms and failure behaviour of Wellington fill-slopes. Although there have been two significant collapses of gully-head fills during rainstorms in the last seven years, the Greater Wellington Regional Council points out that most (99%) of the cut-and-fill subdivisions around Wellington appear to have performed well since they were formed, otherwise more failures would have occurred in the last 40 years.

2.2 Fieldwork

Fieldwork was undertaken to obtain samples of typical fill materials in Wellington, New Zealand. The Wellington fill slope samples were collected form the Priscilla landslides site (Fig. 1) and transferred to DPRI for the geotechnical tests.

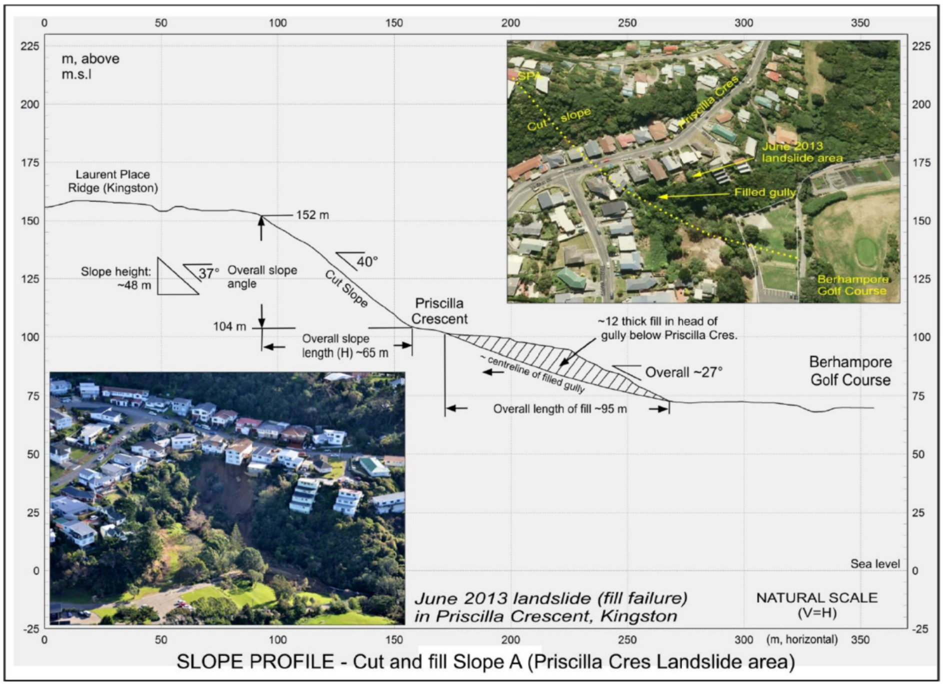


Figure 1. Fill slope failure at Priscilla Crescent, Wellington 2013

2.3 Laboratory testing

An initial set of standard soil classification tests were performed in the GNS laboratory to establish the physical properties of the fill material. Particle-size analysis was conducted through dry sieving methods and indicated that the material contained 60% fine to coarse gravel, 30% medium to coarse sand, with the remaining 10% being fine sands and silts. A second particle size analysis was undertaken using a laser particle sizer on grains finer than 2mm in diameter. The analysis that this finer portion of the material contained very little clay content (below 2 %) with 28- 30% silt and 68-70 % fine to coarse sand. Atterberg limits were determined for finer particle within the fill (below 2mm). The natural moisture content was calculated at 7%.

A series of specialist ring shear tests were undertaken in the DPRI laboratory on remoulded samples with varying particle size and density characteristics. Fill materials were initially sieved to remove large particles and produce samples with three distinct particle size characteristics. Each dry sample was then emplaced into the ring shear to a predetermined sample height. The samples were initially flushed with carbon dioxide before being saturated with de-aired water. For each test the degree of saturation was measured by calculating the B_D value as proposed by Sassa (1985) as the most appropriate method for direct shear testing. In each case the sample was ensured to be fully saturated with $B_D \geqq 0.95$ prior to testing. After saturation each sample was consolidated to a pre-determined normal stress. In some tests, to increase the sample density consolidation was initially undertaken to 400 kPa before being reduced to 200 kPa before shear testing to produce an over consolidation ratio (OCR) of 2.0.

(3)研究成果の概要

3.1 Shear strength Characteristics

Conventional failure envelopes for the fine and medium grained sediments were constructed from ring shear testing at normal loads of 150, 250 and 300 kPa (Fig.2a). The results indicate that the fine grained sediment has lower internal friction angle of about 31.8°, while medium grained sediments has greater one of about 31.8°.

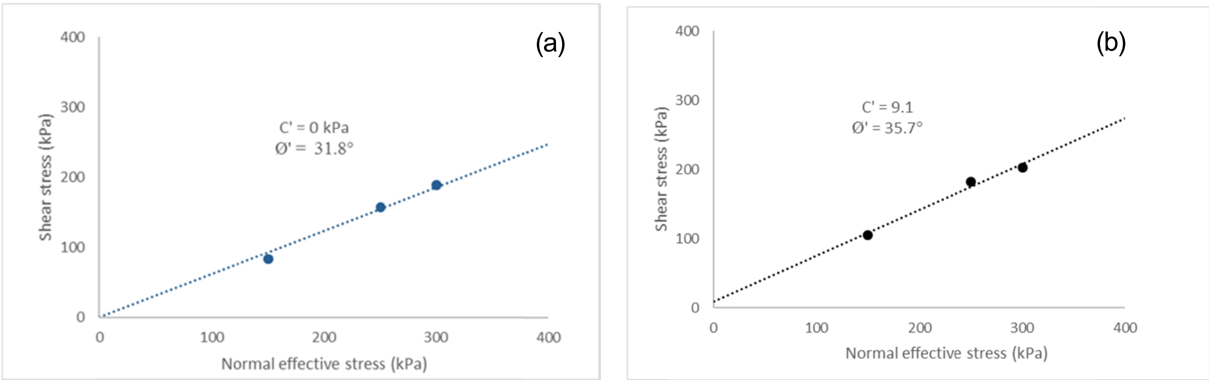


Figure 2. Conventional failure envelopes (a) and (b) for fine and medium grained sediments, respectively.

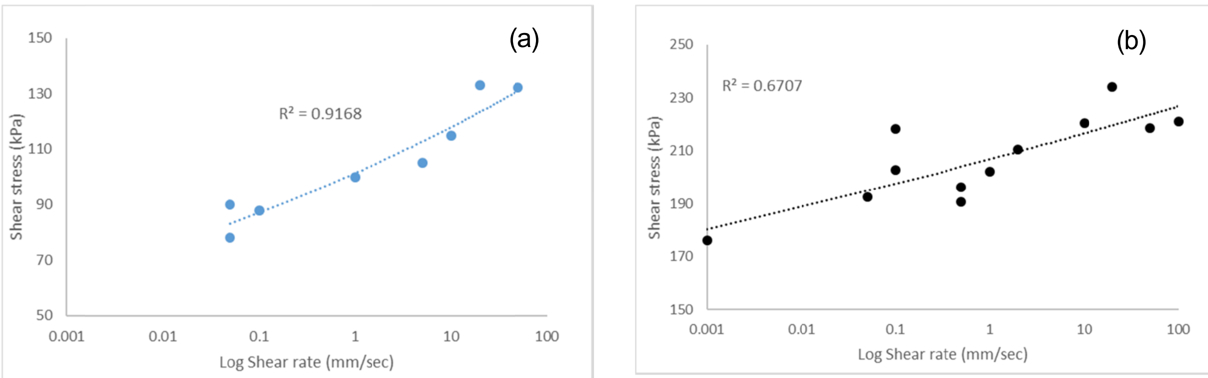


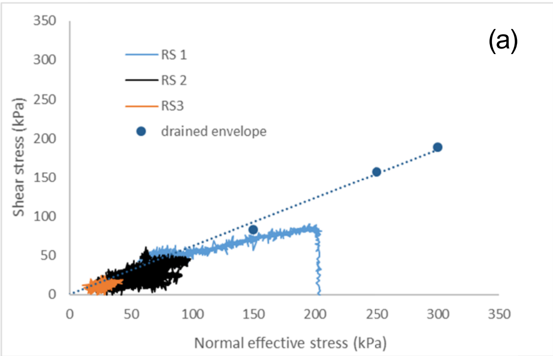
Figure 3 Shear resistances measured at different shear rates for fine grained sediment (a) and for medium grained sediments(b), respectively.

3.2 Shear rate characteristics

We also sheared the samples at different shear rates to check their shear-rate dependences of residual shear resistance. During the test, the sample was at first sheared to residual state at the lowest shear rate available by the employed ring shear apparatus. After that we increased the shear rate by steps and measured the shear strength at each step. The results are plotted in Figure 3, there it is noted that each sample showed a positive effect of shear rate on the residual shear strength, namely, shear resistance increases with increasing shear rate. This kind of positive effect of shear rate indicates that if the landslide may not suffer from accelerating movement, if the landslide is a reactivated one with the sliding surface being the same, in case there is no other factor accelerating the landsliding.

3.3 Behavior during rapid and dynamic loading

A serious undrained shear tests was also performed on these samples in saturated states. The results are presented in Figure 4. It is noted that both samples can surfer from great reduction in shear resistance if sheared under undrained condition. This means that if the landslide was initiated as an initial one, high pore-water pressure could be generated within the shear zone, if the soil layer near the sliding surface were saturated. The generated high pore-water pressure resulted in great reduction in shear resistance, and then would result in the rapid movement of the displaced landslide material. Therefore, it is concluded that the filled slope could suffer from rapid landsliding during earthquake or heavy rainfall, although the materials used in the fill slope have the origin of mudstone.



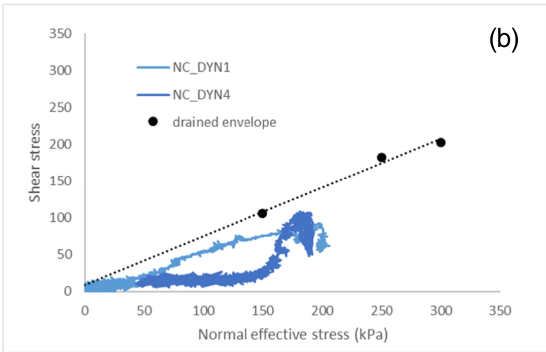


Figure 4 Undrained shear responses for fine grained sediment (a) and for medium grained sediments(b), respectively.

3.4 Further analysis

This study improves our understanding of fill slope failure mechanisms and inform the design of engineered slopes resilient to earthquakes in New Zealand and Japan. To develop a globally significant dataset on the dynamic properties of fill slopes with different geotechnical properties, further analyses on the results are on the progress and will be continued.

(4)研究成果の公表

We will draft one paper based on the results obtained through this joint research, and submit it to an international journal for possible publication.