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# Ring shear characteristics of discontinuous plane

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**Abstract**

Residual shear strength is an essential parameter in evaluating the long-term stability of reactivated landslides in geotechnical engineering. According to previous studies, earthquake-induced landslides may occur on discontinuous planes, such as bedding planes, between weathered and unweathered mudstones having different cementation properties resulting from diagenesis. However, the shear behaviour at the contact surfaces between the cemented and the non-cemented soil layers has not yet been sufficiently investigated. The objective of this study is to elucidate the residual strength characteristics of artificial bedding planes that model the actual behaviour of slip surfaces occurring between two layers with different degrees of cementation. The experimental tests were conducted with a ring shear test apparatus. Additionally, in order to simulate the realistic mechanical behaviour of naturally cemented clay, artificial cementation bonds were created by adding a cementing agent at different ratios to clay slurry. A series of ring shear tests was performed under various conditions on one-layer non-cemented and cemented kaolin samples, respectively, as well as on two-layer specimens composed of one layer each of cemented kaolin and non-cemented kaolin. The test results showed that the residual friction angle of the two-layer combinations of non-cemented and cemented kaolin was approximately 33.6% lower than that of pure kaolin. In contrast, the residual friction angle of cemented kaolin may be as much as 6.2° greater than that of non-cemented kaolin. At cement ratios of up to 2%, the stress ratio of cemented kaolin increased as the shear displacement rate increased. As the cement content was increased beyond 2%, the degree of increase was not significant. These results suggest that the residual strength of cemented kaolin at cement contents greater than 2% is independent of the shear rate.


*Keywords:* Bedding plane; Discontinuous plane; Residual strength; Peak strength; Clay; Cementation; Rate effect; Stress dependency (**IGC:** D06, E06)

## 1. Introduction

Landslides in soils such as shale, sandstone, and mudstone occur frequently in many parts of the world. The occurrence of earthquake-induced landslides in Japan has increased since the Mid Niigata Prefecture Earthquake of 2004. The scale and movement of earthquake-induced landslides, the constituent materials, and the locations of slip surfaces are quite different from those of rainfall-induced landslides. Fig. 1 shows a typical case of an earthquake-induced landslide that occurred due to the Mid Niigata Prefecture Earthquake. The landslide occurred on the boundary between weathered and unweathered mudstone (PWRI, 2006). It should be noted that the majority of landslides occur along discontinuous surfaces, such as bedding planes, where the strength of the upper layers differs from that of the lower layers. However, the strength and deformation properties of the contact surfaces between different soil layers during static and dynamic loading remain to be clarified (Sassa et al.,

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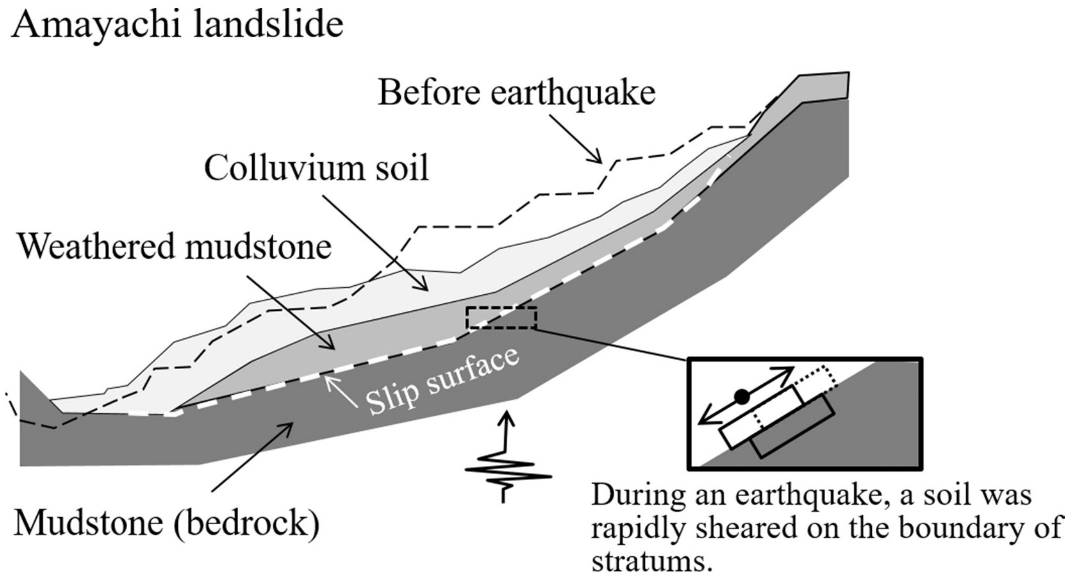


Fig. 1. Typical case of earthquake-induced landslide in the 2004 Mid Niigata Prefecture Earthquake (PWRI, 2006).

1995; Onoue et al., 2006; Wakai et al., 2010; Kinoshita et al., 2013).

An important feature of all naturally cemented clays is the bonding that takes place between particles as a result of diagenesis. This occurs because of carbonate precipitation and the growth of carbonate crystals on the soil grains. Natural cementation increases the resistance of soil to deformation. Therefore, when the cementation is broken, failure will occur, accompanied by a significant magnitude and rate of subsequent deformation. Landslide soils possess the mechanical properties of cemented soil owing to diagenetic bonding over an extended period (Suzuki et al., 2007). This results from the precipitation of the cementing agents in marine and arid environments, weathering, or long-term crystal growth between grains (Sangrey, 1972). The unique behaviour of these soils has been attributed to bonding or to the natural cementation between particles that developed in situ soon after deposition. The existence of cementing binders can cause chemical binding that results in overconsolidation. This leads to behaviour similar to that of overconsolidated clays, such as strain softening and higher initial stiffness.

Many researchers have studied the behaviour of artificially cemented soils in order to model naturally cemented soils. To simulate the behaviour of natural clay cemented over many years, artificially cemented clay can be created by mixing clay with a small amount of Portland cement or similar agents. Using this method, laboratory cementation bonding occurs at a much faster rate than that of natural clays cemented via diagenetic processes. In recent decades, a number of investigations have been conducted on the stress-strain relationship and strength properties of cemented soils using triaxial, direct shear, unconfined compression, and ring shear tests conducted on artificially cemented samples. There are many common mechanical characteristics amongst the different types of cemented soils, such as yield stress, initial stiffness, peak strength, residual strength, and dilatancy. According to the literature, the concept of aging often refers to the cementation of clays developing over many years. The mechanical behaviour of aged clay is characterized by three main factors: delayed compression and cementation over a long period of geological time, a consolidation yield stress higher than the effective overburden pressure, and “stress overshooting” in an e-log p relation (Bjerrum, 1967). Leroueil and Vaughan (1990) revealed that the mechanical behaviours of naturally cemented soils, such as claystone, sandstone, and weak rocks, are similar, even when the cementation results from different causes. Consequently, artificially cemented clay samples are expected to simulate many of the characteristics of naturally cemented clays. The effects of bonding in artificial clays are only significant for stress levels below an apparent pre-consolidation stress value. They are considered to be sensitive to changes in stress and the duration of loading during testing. It has been shown that artificially and naturally bonded soils were comparable with respect to yield compression stress and strain-softening behaviours (Cuccovillo and Coop, 1999). From these experimental studies, the behaviour of artificially cemented kaolin was found to be qualitatively similar to the behaviour of sensitive natural clays (Sangrey, 1972; Burland, 1990). Fisher et al. (1978) stated that cemented Drammen clay behaves as a non-cemented clay with an overconsolidation ratio (OCR) of about 1.7. Kasama et al. (2000) indicated that the failure envelope of cemented clay is parallel to that of non-cemented clay based on the

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