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Interface shear strength between geosynthetic clay liner and covering soil on the embankment of an irrigation pond and stability evaluation of its widened sections

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Abstract

Geosynthetic clay liners (GCLs) are typically used for widening sections of an embankment. They are also used as low permeability liners to minimize water leakage from reservoirs such as irrigation ponds. However, few investigations have been carried out on the specific properties of GCLs, such as granulated bentonite sandwiched between geotextiles, their internal shear strength, and the shear strength at the interface between a GCL and an embankment body. In this study, a series of direct box shear tests were performed to determine the shear strength properties of bentonite and compacted soils as well as at the interface between a GCL and bentonite or compacted soil. In addition, a series of field-loading tests were conducted to investigate the failure behaviour of an embankment body containing a GCL when changes in the water content of the bentonite of the GCL in a real embankment occur. Furthermore, the stability of widened embankment bodies that incorporated GCLs were evaluated. The main conclusions of this study are as follows: (1) The shear strength of the interface between the covering soil and geotextiles varied according to the soil type, geotextile type, and the submergence period, (2) the maximum safety factor was observed at the interface between decomposed granite soil and the geotextiles, while the minimum safety factor was observed at the interface between the bentonite and the geotextiles, and (3) the influence of GCLs on the instability of a widened embankment was extremely small.

Keywords: Embankment; Geosynthetic clay liner; Bentonite; Interface shear strength; Field test; Slope stability (**IGC**: D06/E06/H04)

1. Introduction

There are approximately 210,000 irrigation ponds in Japan, some of which have significantly deteriorated over their life span. For instance, the stability of an embankment body diminishes when water leaks or deformation of the embankment occurs. Hence, it is essential to repair the damaged portions affected by deterioration to prevent the failure of irrigation ponds. Generally, repairs involve the use of high-quality clay as a water barrier in irrigation ponds. However, as the banking or covering soil in the embankment is subject to erosion, it is considered difficult to replace the soil lost due to erosion. Recently, a method that involves the widening of a section of the previous embankment over a geosynthetic clay liner (GCL; Fig. 1) has been developed in the field of agricultural civil engineering (Natsuka et al., 1993; Bouazza, 2002; Hara et al., 2009).

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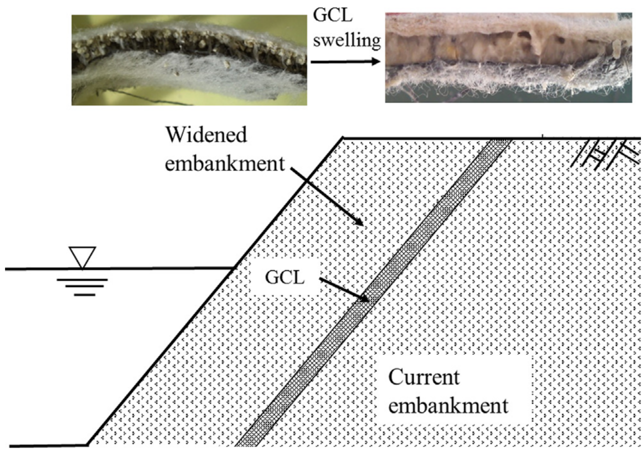

Fig. 1. An embankment widened across a GCL.

GCLs consist of layers of bentonite sandwiched between woven and non-woven geotextiles using needle-punches (Daniel and Koerner, 2007). They prevent leaks in irrigation ponds by permitting the infiltration of water, which causes the bentonite to swell. Several studies have verified the engineering application of bentonite for solving advanced environmental problems (Komine and Ogata, 1994; Kodaka and Teramoto, 2009). In addition, GCLs containing expansive clay minerals such as montmorillonite have also been used in waste disposal sites; this confirms their chemical durability and their performance as a long-term barrier (Malusis and Shackelford, 2002; Lee and Shackelford, 2005; Katsumi et al., 2008).

The internal shear strength of needle-punched GCLs has been determined and their resistance against sliding has been demonstrated (Gilbert et al., 1996; Stark and Eid, 1996; Fox et al., 1998a; Zornberg et al., 2005; Fox, 2010; Bacas et al., 2013; Fox et al., 2015; Fox and Stark, 2015). It was proposed that the strength of a GCL depends on the type of material used for the geotextiles as well as the connections between the needle-punch and the geotextiles. Furthermore, the peak and residual shear strengths of reinforced GCLs were influenced by the rate of shear displacement due to excess pore pressures on bentonite and the pull-out or rupture of the needle-punched fibres.

Moreover, the peak shear strengths of hydrated reinforced GCLs were lower than those of dry reinforced GCLs (Bacas et al., 2013). While the time required to achieve the complete hydration of a GCL depends on the drainage conditions, it generally decreases with increased normal stress (Gilbert et al., 1996; Fox and Stark, 2015). A few studies on the interface shear strength between GCLs and geomembranes (GM) have been carried out, and the results demonstrated that the interfaces typically have low shear strengths due to the extrusion of bentonite from the hydrated GCL (Seo et al., 2007; Vukelic et al., 2008; Chen et al., 2010; Saito et al., 2013). Further, Athanassopoulos and Yuan (2011) reported a correlation between the peel and internal shear strengths of a GCL; they concluded that the peak internal shear strength was a function of peel strength in the hydrated needle-punched GCL. In addition, Hurst and Rowe (2006) demonstrated that the average bonding peel strength of a needle-punched structure was not affected in a hydrated GCL under an applied normal stress of 14 kPa for a period of up to 15 days. It was observed that the internal shear strength of a GCL increased due to needle-punching (Zornberg et al., 2005). Thus, it would seem evident that the needle-punched structure improved the internal shear strength of the GCLs. However, a study by Fox (2010) indicated that the internal shear strength of GCLs also depends on the product type. As mentioned above, previous studies have demonstrated the characteristics of the internal shear strength and swelling behaviour of GCLs. Nevertheless, to evaluate the stability of embankments over GCLs, it is necessary to understand the characteristics of the shear strength of the interface of each soil layer. Direct box shear tests have been conducted in several previous studies to determine the behaviour of the interface between soil and woven or non-woven geotextiles (Lee and Manjunath, 2000; Goodhue et al., 2001; Anubhav and Basudhar, 2010; Khoury et al., 2011). Goodhue et al. (2001) have highlighted the importance of conducting a shear test that simulates the field conditions as accurately as possible. Therefore, in this study, a direct box shear test was conducted within a low normal stress range to determine the shear strength of the interface between the widened embankment soil and a GCL under submerged conditions. No full-scale field tests have been carried out to clarify the behaviour of the embankment laid with a submerged GCL during the construction process. In fact, to our knowledge, the characteristics of the shear strength and the stability of embankments built over GCLs have yet to be adequately studied.

The purpose of this study is to determine the stability of embankments on GCLs, with the intention of providing a safe, stable, and economic method for repairing irrigation ponds using GCLs. A series of shear tests of GCLs were conducted as a novel approach for studying these materials. In summary, this study aims to elucidate the characteristics of the internal shear strength of GCLs without a needle-punched structure as well as the characteristics of the interface between a GCL and the embankment soil. An improved direct box shear test was employed to determine the shear strength of the interface between the soil and GCL using decomposed granite soil and bentonite collected from a GCL as samples. The bentonite was subjected to a consolidated constant pressure direct box shear test under different submersion conditions. Both field tests and direct box shear tests were carried out to clarify the shear strength of bentonite and the shear strength of the interface between bentonite or embankment soil and the geotextiles. Finally, the stability of embankments that incorporated a GCL was evaluated. It should be noted that a study of the issues related to seepage in an embankment and its effects on the water barrier due to the presence of bentonite are beyond the scope of this paper.