11th Mercer lecture on
Geosynthetics for construction on soft foundation soils
Extended Abstract

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Abstract This lecture examines the progress made in the last few decades concerning the use of geosynthetics for aiding in the construction on soft soils. Consideration is given to different soft soils ranging from peat to rate-sensitive soft clay and silt. Both relatively elastic and rate-sensitive reinforcements are examined. Consideration is given to basal reinforcement, prefabricated vertical drains, and embankments with reinforcement and other supports such as piles. Particular emphasis is placed on advances since the senior author's 2002 Giroud lecture.

Keywords: Geosynthetics, soil improvement, field performance, numerical modelling

1 Introduction

This lecture follows the senior author's 40-year exploration of the use of geosynthetics to aid the construction of embankments on soft and/or difficult soils. The lecture, named in honour of Dr. Brian Mercer OBE, FRS (1927 – 1998) was an English engineer, inventor and businessman and the inventor of modern Tensar geogrids (a breakthrough in geosynthetic reinforcement).

The lecture is built around three key points:

1. Soil reinforcement is well-established as a cost-effective alternative to, or augmentation of, traditional construction methods.
2. In the design of embankments on soft soils, reinforcement can play a key role and understanding its properties and characteristics is critical to success. But also, while geosynthetics are very useful, they are not magical. They obey physical laws and, as with all engineering materials, we need to design properly.
3. While geosynthetic properties and characteristics are important, we must not get so absorbed in the geosynthetics that we forget the soil mechanics; it too is an essential consideration for ensuring good long-term performance.

The topics start fairly simply and then build-up in complexity to lead to the final topic highlighting the need for current research into pile-supported embankments to pay more attention to the lessons of the past 40 years as presented in this lecture.

2 Embankments on soils where reinforcement is most critical during construction

One of the simplest and earliest applications for geosynthetic reinforcement was its use as basal reinforcement of embankments on peat either underlain by a competent layer or a layer or very soft clayey silt. The discussion is built around the performance and analysis of the geotextile reinforced Bloomington Road embankment on 6.9 m of fibrous peat (average water content of 785%) underlain by sand (Rowe et al. 1984a, b) and the geogrid reinforced Hubrey Road embankment built on 1.9 m of fibrous peat (water content of 250-700%) underlain by ~ 2.8 m of very soft organic silt (water content of 250-480% and $4 \leq s_u \leq 12$ kPa) underlain by sand (Rowe and Mylleville, 1996). It then discusses design methods (Rowe and Soderman, 1985a, 1986) that have now been successfully used for 35 years. These design methods were developed based on calibrated numerical analysis. A key characteristic of successful modelling of peat is the use of effective stress parameters and the consideration of the significant pore pressure dissipation during construction necessary to gain sufficient effective stress and hence strength to sustain the loads induced by the embankment fill. In these cases reinforcement aids in developing stability and allowing higher embankment heights but does very little to reduce the significant consolidation settlements accompanying construction over peat.
The lecture then moves to basal reinforcement of embankments on soft clay where undrained stability during construction to the final height is the most critical design consideration. The discussion begins by looking at the performance and numerical analysis of an unreinforced and a reinforced embankment on soft organic clay at the Almere embankment (Rowe and Soderman, 1984). It then discusses design considerations for these embankments on soft clay using basal reinforced embankments (Rowe and Soderman, 1985b, 1987).
While basal reinforcement alone can be sufficient to allow construction on some soft clayey soils, often is not sufficient alone. In these cases, the combined use of prefabricated vertical drains (PVDs) with basal reinforcement is shown to give substantially better performance than either basal reinforcement or PVDs alone. This is illustrated by the predictive modelling of Li and Rowe (2001a) and the field performance of four test embankments reported by Da Silva *et al. (*2017)

3 Rate sensitive soils and reinforcement

In the cases examined in the previous section, once the embankment was constructed, pore pressures in the foundation soils dissipated with time post-construction and the reinforcement became less critical to embankment stability. Monitored embankments for these cases typically show a reduction in strain in the reinforcement with time as the effective stress increases and the soil gains strength due to pore pressure dissipation. However, while that situation occurs often, in 35% of the field cases examined by Crooks et al. (1984), the pore pressures below the embankment increased significantly after the end of construction. For embankments on these rate-sensitive clays, the most critical time for stability is not the end of construction but sometime after the end of construction when the pore pressures reach a maximum value and hence the effective stress and strength are at a minimum. This has led to embankment failures weeks or more after the end of construction. This is a problem on many soils in Canada and the senior author is familiar with cases where there has been no apparent dissipation of pore pressures in 50 years after the end of construction. This is not because there is no pore pressure dissipation. It is because of destructuring of the clay generating pore pressures as quickly as they dissipate and the consequent maintenance of high pore pressures. To illustrate the importance of rate-sensitive soils, this part of the lecture begins with the examination of modelling of rate-sensitive soil (Hinchberger and Rowe 1998) and the field performance and modelling of a reinforced test embankment constructed on a rate-sensitive soil in eastern Canada that was intentionally built to above its predicted long-term stability to allow monitoring of its post-construction failure (Rowe et al., 1995; Rowe & Hinchberger, 1998. The lecture then discusses design methods that can be adopted for basal reinforcement of embankments on these rate-sensitive soils which often have a liquidity index ≥ 1 (Li and Rowe, 2002; Rowe and Li, 2002; Hinchberger and Rowe 2003).

The viscosity of geosynthetics and the related time-dependent behaviour is not especially critical for embankments on soils where there is strength gain post-construction and the reinforcement becomes less critical with time. However, that is not the case on rate-sensitive soils where pore pressures increase post-construction and the most critical time for stability is days, weeks, or even months after the end of construction. In these cases the reinforcement strains do not reach a maximum at the end of construction but increase with time until either an equilibrium is reached or the reinforcement fails as it did in the test embankment described by Rowe et al. (1995). The lecture then examines this case (Taechakumthorn and Rowe, 2012) and provides a reference to design guidelines for rate-sensitive reinforcement used on rate-sensitive soils (Rowe and Taechakumthorn, 2008, 2011).

4 Column/pile-supported embankments

The last section of the lecture begins by discussing the floating column supported embankments on soft soil. It compares and discusses both the observed field performance (Briançon and Simon, 2012) and the numerical modelling (Rowe & Liu, 2015**)** of embankments with an out without geosynthetic reinforcement and with both geosynthetic reinforcement and PVDs. Consideration is then given to the effects of PVDs (Li and Rowe, 2015a) and rate-dependent reinforcement (Li and Rowe, 2015b, 2016).

The lecture concludes with a discussion of end-bearing column supported embankments, including a discussion of the critical nature serviceability limit state in the longer-term (King et al, 2017a, b), soil arching and the critical height (King et al. 2019), the ground reaction curve (King et al. 2017c, 2020) and this all highlights the need to pay more attention to the lessons from the past 40 years that are presented in this lecture.

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