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A review of the geotechnical characteristics of loess and loess-derived soils from Canterbury, South Island, New Zealand

K. Yates*, C.H. Fenton, D.H. Bell

Department of Geological Sciences, University of Canterbury, Christchurch, New Zealand

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ABSTRACT

Loess and loess-derived soils cover much of Canterbury, from the foothills of the Southern Alps to the Pacific Coast. These deposits are of variable thickness, from a few metres up to 40 m at the base of slopes on Banks Peninsula. In many areas the primary, air-fall loess has been reworked by slope processes to form a loess colluvium. Although primarily silty, these soils contain up to 45% clay, giving rise to low plasticity clay behaviour. These deposits are relatively dense, with dry densities of 1.6 t/m^3 and 1.8 t/m^3, hence they do not display collapse behaviour common to other loess deposits around the World. Loess and loess-derived soils across Canterbury have high dry strength but weaken rapidly with small increases in moisture content. In the wetter parts of the region, on Banks Peninsula in particular, periodic wetting leads to a variety of slope failures related to internal erosion (tunnel gullying) and rapid loss of shear strength (debris flows, soil slides and rotational failure). Elsewhere in the drier parts of South Canterbury loess deposits commonly form vertical exposures and evidence of slope instability is comparatively rare. The current understanding of the geotechnical characteristics of these deposits is based on a limited number of studies with restricted geographic extent. Thus a full understanding of regional and stratigraphic variability is yet to be established. Macroscale heterogeneities, including fissuring, development of fragipan cemented horizons and stratification, indicates that, as well as the general behaviour presented in this paper, there may also be significant local variation. In addition, the effects of soil microstructure, including bonding and particle shape and orientation, on overall soil behaviour are recognised, but have yet to be investigated in detail.

1. Introduction

Loess and loess-derived soils cover much of the South Island, New Zealand. The most extensive deposits cover the foothills of the Southern Alps, and lowlands of the Canterbury Plains (Fig. 1). Loess-derived soil includes any material that has been formed as a result of reworking of primary air-fall loess. We use the term “loess deposits” collectively to denote both loess and reworked loess-derived soils. Loess deposits across Canterbury are yellowish-brown deposits with predominantly silt-sized grains. Sand content typically comprises fine, angular particles. Both the sand and clay contents vary depending on location and extent of reworking. Loess deposits often exhibit well-defined vertical fissuring and less well-defined horizontal fissuring (Raeside, 1964). The thickness of loess deposits varies geographically, with deposits > 1 m covering approximately 10% of the South Island (Fig. 1). Loess deposits have been observed to reach up to 20 m and 40 m on the lowlands south of Timaru (South Canterbury) and on Banks Peninsula, respectively (Bell and Trangmar, 1987). The thickest deposits occur at the base of slopes, where colluvial reworking creates an apron of slope-derived soil (Bell and Trangmar, 1987).

When dry, loess deposits can form vertical exposures with fissuring within the soil mass controlling the strength and stability. However, these deposits are sensitive to changes in moisture content and the soil matrix can weaken rapidly upon small (2%–3%) increase in moisture content leading to reduction in shear strength and erosion (Hughes, 2002; Jowett, 1995; McDowell, 1989). Currently the relationship between moisture content and shear strength and the influence of microstructure and soil suction is not well understood. Strength loss can be exacerbated by susceptibility to clay dispersion and erosion making loess deposits subject to instability on slopes (Bell et al., 1986). The loess deposits found on Banks Peninsula (Fig. 1) have historically been susceptible to widespread slope movement, primarily associated with periods of intense rainfall. During the 1945 and 1975 rainstorm events extensive movements were recorded across Banks Peninsula (Alley, 1966; Hutchinson, 1975). Observed failures include soil creep, debris

* Corresponding author.
E-mail addresses: katherine.yates@pg.canterbury.ac.nz (K. Yates), clark.fenton@canterbury.ac.nz (C.H. Fenton), david.bell@canterbury.ac.nz (D.H. Bell).

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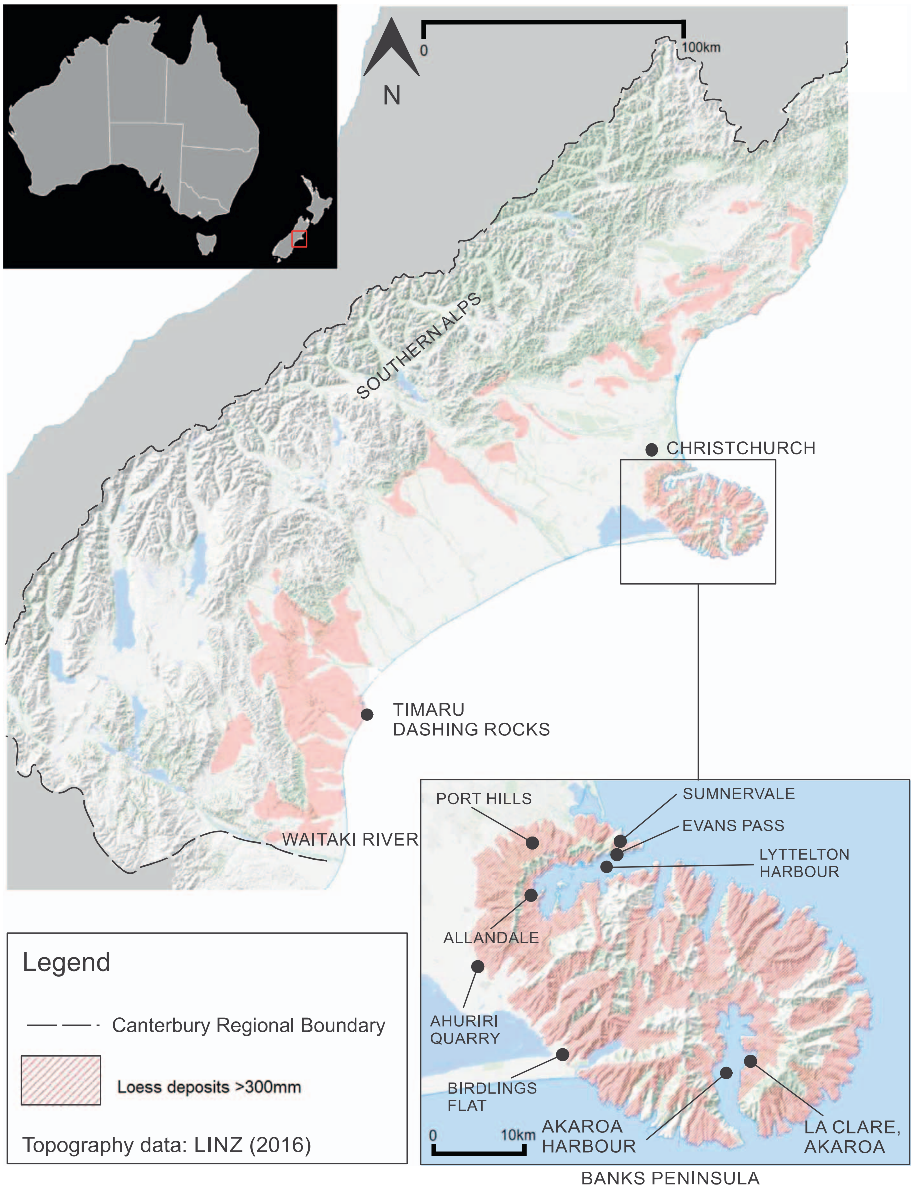

Fig. 1. Distribution of loess deposits in Canterbury. Localities discussed in the text are annotated. Modified from Bruce et al. (1973), Raeside (1964) and Griffiths (1973).

flows, tunnel gully erosion and mass movement (Fig. 2) (Bell and Trangmar, 1987).

Despite the extensive outcrop of loess and loess-derived soils across Canterbury, there have been a relatively limited number of studies of their geotechnical properties. The majority of these investigations have been Masters Dissertations performed at the University of Canterbury (*e.g.*, Glassey, 1986). These studies are generally limited in scope, investigating primarily index properties and aspects of tunnel gullying, and erosion. Due to limited geographic distribution of these studies, regional and stratigraphic variability of these characteristics are not well understood. Furthermore, to date there has been limited compilation of previous research and as such there is no succinct geotechnical characterisation of Canterbury loess deposits.

The purpose of this paper is to provide a synthesis of the origin, distribution and geotechnical properties of loess and loess-derived soils across Canterbury, New Zealand. The depositional, stratigraphic, structural and mineralogical characteristics are considered first. Geotechnical properties for different deposits are then compared. The relationship between shear strength, microstructure and moisture content is then explored.

2. Depositional environment of Canterbury loess

New Zealand loess has been formed from aeolian transportation and deposition of glacially-derived rock flour (Bell et al., 1986; Bell and Trangmar, 1987; Bruce, 1973; Griffiths, 1973; Raeside, 1964; Sparrow, 1948). Although a detailed temporal correlation between loess deposition and glaciation has not been well defined, loess deposition and formation in South Canterbury has been broadly correlated with warming trends in oxygen isotope profiles during the Late Pleistocene (Tonkin et al., 1974). Furthermore, an increase in fluvial and aeolian erosion and a subsequent redeposition of glacial-fluvial deposits during glacial recession coincide with loess deposition (Ives, 1973; Smalley and Fagg, 2014; Sparrow, 1948).

Mineralogical composition indicates that the main source of loess deposits in the region was rock flour eroded from the Southern Alps (Raeside, 1964; Sparrow, 1948; Young, 1964). Silt-sized grains are thought to have been initially transported fluvially from alpine catchments to braided river banks during periods of ice retreat during climate warming (Griffiths, 1973). These deposits were then transported by wind and redeposited on hilly topography during colder phases (Ives, 1973; Smalley and Fagg, 2014). The presence of sponge spicules