IOP Conf. Series: Earth and Environmental Science **17** (2014) 012264 doi:10.1088/1755-1315/17/1/012264

Seasonal slope surface deformation measured with TLS

L Fan, J Smethurst, W Powrie and A Sellaiya

Faculty of Engineering and the Environment, University of Southampton, UK

Lei.Fan@soton.ac.uk

Abstract. In temperate European climates, soil water removal due to vegetation transpiration peaks in summer and soil rewetting from higher levels of precipitation occurs in winter. In clays of high plasticity, the seasonal cycles of drying and wetting cause the soil to experience a volumetric change, resulting in seasonal shrinking and swelling. For a clay slope exhibiting volume change, such behaviour can lead to excessive deformation and could contribute to strain-softening and progressive slope failure. This can in turn cause traffic disruption and loss of life if roads and railways are founded on or surrounded by such slopes. This paper discusses the driving forces of seasonal surface movement, in particular the role of vegetation, and presents the use of Terrestrial Laser Scanning (TLS) to measure the surface movement of a lightly vegetated London Clay slope near Newbury, UK. Two TLS scans were carried out in early and late summer respectively, representing relative wet and dry conditions of the slope. Continuous field measurements of soil water content in upper layers of the slope were obtained from TDR ThetaProbes already installed at the site. The water content data are used to support the results obtained from TLS by indicating the likely volumetric change in the soil due to loss of water.

1. Introduction

Slopes of high plasticity clay are vulnerable to deformation due to seasonal fluctuations in soil water content and associated shrinking and swelling processes [1,2]. Vegetation contributes to the process through transpiration, and may cause up to 50mm of annual vertical movement [3]. This can lead to major serviceability problems, such as excessive vertical displacement of a railway track. It could also promote progressive failure of slopes due to cyclic changes in soil stresses [4]. Inclinometers and extensometers are usually used to monitor horizontal and vertical displacements of a slope. These conventional instruments work effectively in measuring deformations but have several drawbacks. They have to be installed on site intrusively and may be expensive. Also, maintenance is a major issue as the instruments may lose their functionality. As an alternative, remote sensing techniques can be considered although they remain largely unexplored for monitoring engineered slopes.

In the last decade, Terrestrial Laser Scanning (TLS) has attracted increasing attention from academia and industry. The technique allows a large quantity of accurate topographical information to be recorded with a high spatial resolution over a relatively short period of time. These features suggest that it has a great deal of potential in detecting surface displacements. A number of scientists have successfully applied TLS for landslide monitoring and surface change detection [5].

This paper reports the use of TLS to measure the displacements of a cut slope caused by seasonal changes in water content. Two survey campaigns were carried out on 11 June and 2 September 2010 respectively, representing relative wet and dry conditions of the slope. Field measurements of soil water content in upper layers of the slope are provided, which indicates that the slope surface was shrinking.

2. Site

The slope chosen in this study is a cut slope on the A34 Newbury bypass in southern England (figure 1; OS grid reference SU455652). The slope is east facing, 8 m high and 28 m long. The cut was constructed in 1997, and is entirely within the London Clay. After the cutting was excavated, up to 0.4m of topsoil was placed over the slope surface to facilitate the planting of vegetation. The vegetation on the slope was mainly grass of various depths at the time the survey was carried out. There were also a number of sparse shrubs growing in the upper part of the slope and mature trees just beyond the slope crest.

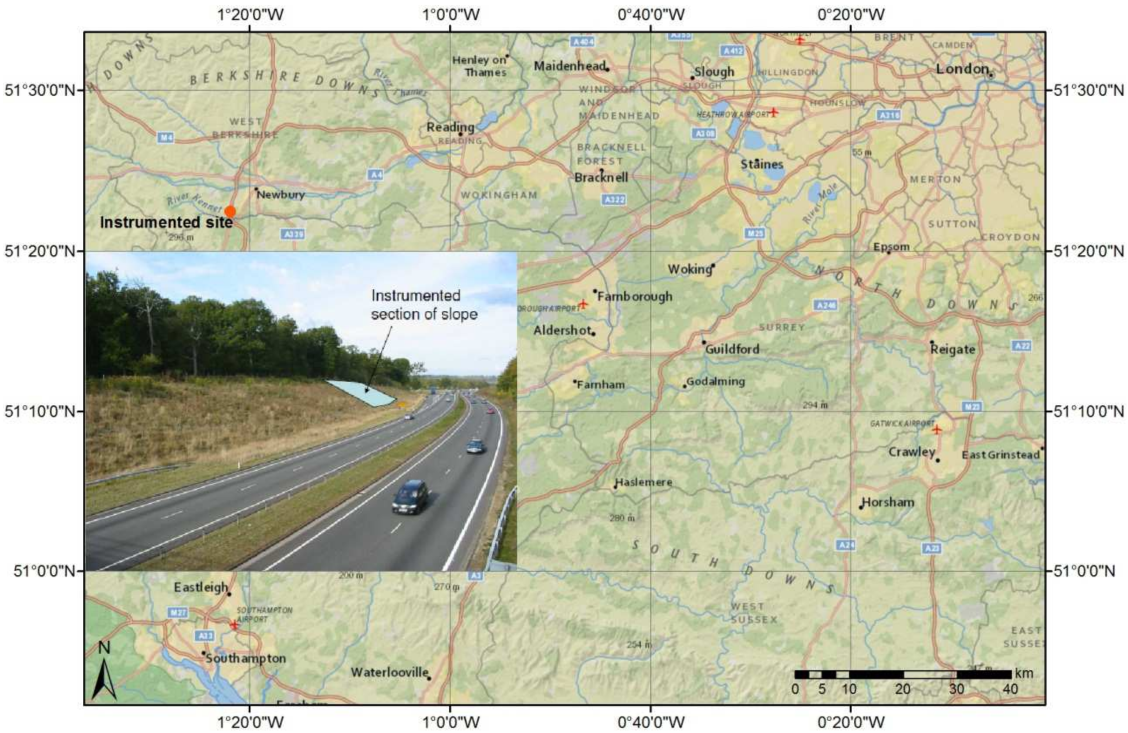

Figure 1. Location and photo of the site.

Instrumentation was installed in 2002 and 2003 to monitor soil water content, pore water pressure and rainfall. Arrays of time domain reflectrometry (TDR) probes were used to measure soil water content. Volumetric water content (=volume of water / total volume) recorded between 2003 and 2008 follows a seasonal pattern [2]. This can lead to a seasonal deformation for a high-plasticity slope, in particular where vegetation is present. Evaporation from the soil surface will draw moisture out of the soil profile in the warm summer period. Water uptake by plant roots from the surrounding soil can be significant in dry summers, causing additional shrinkage. Evapotranspiration is the sum of soil evaporation and vegetation transpiration, and depends on plant type, climate, soil characteristics and soil water content [2]. During wet winters, the soil swells due to rainfall infiltration. The vertical deformation due to water removal can be over 40mm for a tree-covered clay slope and about 10mm for a grass-covered slope [6]. The variation of soil water content at the Newbury cut in 2010 is illustrated in figure 2. The measurements suggest a decrease of water content form 11 June to 2 September, indicating that the slope suffered shrinkage during this period.

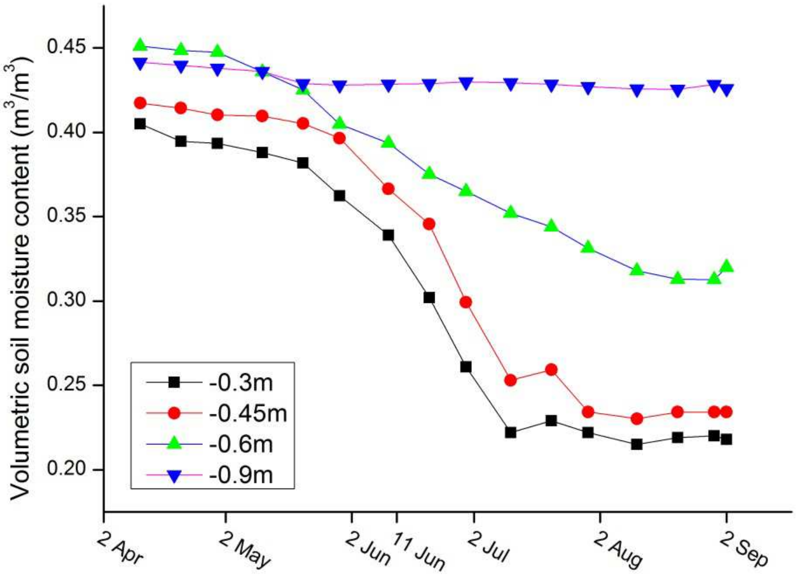

Figure 2. Volumetric water content measured using TDR ThetaProbes within the weathered London clay at group A at the depths below ground level indicated (the locations of the instrumentation can be found in [1].).

3. Terrestrial Laser Scanning

3.1. Data acquisition

A single-return Leica ScanStation 2 was employed to scan the slope. It has a positional accuracy of 6mm within a scan range of 50m, and a scan rate of up to 50,000 points per second. It also features a 360° (horizontal) and 270° (vertical) field-of-view.

Prior to implementing the laser scanning, an accurate control network was set up for registration and geo-referencing. Accurate geo-referencing is extremely important for deformation detection because multi-temporal survey data can be compared only if they are in the same coordinate system. For geo-referencing, two site benchmarks (known points) were located on a nearby farm access bridge. A Leica total station was setup over one known benchmark and aligned due south with another benchmark on the bridge, to create the local coordinate system. The total station was then used to record the coordinates of the centres of four Leica targets (represented by the points marked HDS in figure 3) which were strategically placed around the scan locations (figure 3) to enable individual scans in a single survey campaign to be registered. The same procedure was applied to the laser surveys in June and September. This allowed the multi-temporal point clouds to be geo-referenced to the same local coordinate system. The bridge piers are on large concrete pad foundations installed at 2m depth below the ground level, which are below the seasonally affected zone of clay soil. Also, the bridge had been in service for over ten years, and its major movements were likely to be thermal related and much smaller than shrinkage of the soil. It was therefore reasonable to assume that the movement of the two benchmarks was minimal between two surveys.

Since the effect of low vegetation on the TLS surveys was unknown, the grass in the upper part of the slope (the area between Patch_2_2 and Patch_2_1 in figure 3) was trimmed before scans took place. The grass in the remaining area was not cut so as to investigate the effect of grass on surface change detection. Four scan positions were used to achieve a complete coverage of the slope section of interest.

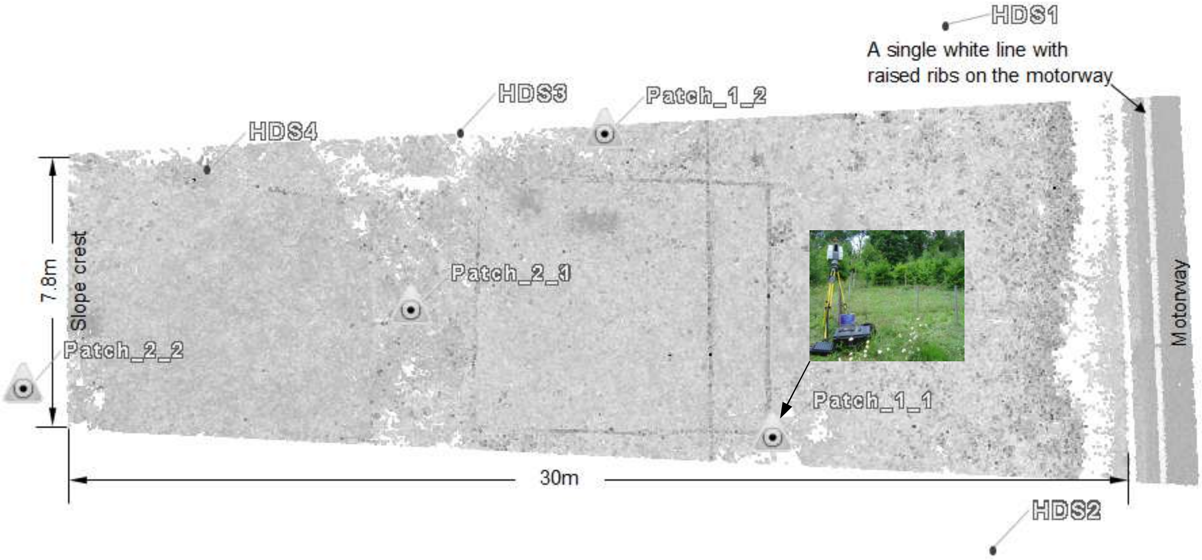

Figure 3. A plan view of the slope scanned; scan positions and Leica targets are indicated by the labels Patch and HDS respectively.

3.2. Data processing

The initial data processing was carried out in Leica Cyclone® 8.3, which is the official software to visualize and manipulate point clouds obtained from Leica laser scanners. It was used to register multiple scans from different scan locations into an integrated point cloud, based on the coordinates of the centres of the Leica targets. The total station measurements were imported into Cyclone® where the point clouds were geo-referenced to the local coordinate system determined by the two benchmarks on the nearby bridge. Since the grass in the upper part of the slope was trimmed very close to the ground level, the datasets representing this part were used for deformation analysis. The datasets for remaining areas were used for assessing vegetation effects, which are not discussed in this paper. The point clouds representing the upper part were exported from Cyclone® and then imported into MATLAB® where the surface differences were analysed and visualised.

4. Results

To obtain surface deformation, multi-temporal point clouds were first converted into separate Digital Elevation Models (DEMs). By differentiating these, the displacements were obtained. There are many methods to create a Digital Elevation Model (DEM). In this paper, Moving Average (MA) was used. In this method, the point clouds were converted into 0.5m × 0.5m grids. The mean elevation of all the points that fell into an individual grid was assigned to the grid. Since the MA could reduce measurement errors and the effect of local surface variation (roughness) through averaging, it was considered a suitable method to reveal displacements of very small magnitude.

Figure 4 illustrates the surface difference of the slope between June and September 2010 for the upper part of the Newbury cut. A consistent deformation pattern (shrinkage) is present. The average displacement is about 15mm, which is of the same magnitude reported by Scott et al [6]. for a high-plasticity clay railway embankment, and thus seems quite reasonable for a grass-covered slope with mature trees at its crest. The hard shoulder of the motorway was also recorded by the scanner in both survey campaigns. There was a continuous single white line with raised ribs every few hundred millimetres between the hard shoulder and the carriageway. The ribs provide audible and tactile warnings when the line is being crossed by a motor vehicle. These ribs were identified in the point clouds of June and September and used to assess the quality of the geo-referencing, which further verified the deformation shown in figure 4. Three adjacent ribs were separately selected from the survey data in June and September and then compared. The comparison showed an average positional

IOP Conf. Series: Earth and Environmental Science **17** (2014) 012264 doi:10.1088/1755-1315/17/1/012264

(X and Y directions) difference of about 3mm and an elevation difference of 5mm. The hard shoulder surveyed in September was 5mm below that in June. This difference in elevation might be caused by geo-referencing errors or the shrinkage of the clay underneath the carriageway as the pavement structure was not that deep. In either case, the measurements indicated the slope to have shrunk by about 10 to 15mm.

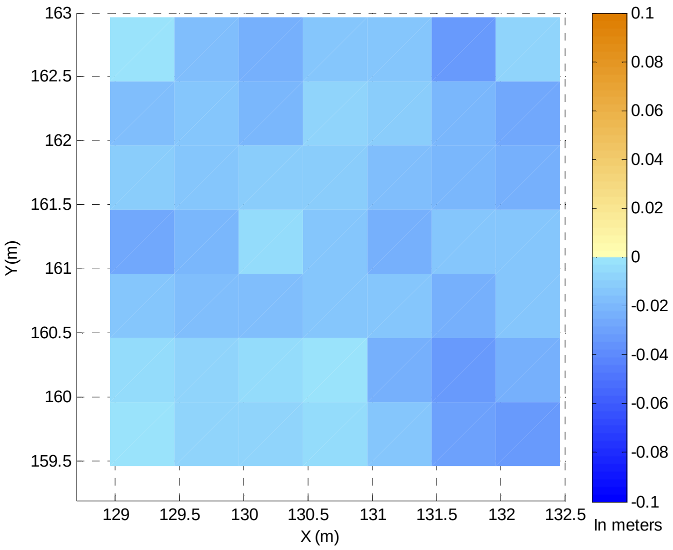

Figure 4. Slope surface displacements using the Moving Average with 0.5m × 0.5m grid size.

5. Discussion

The results in this paper suggest that TLS offers an alternative way of measuring small displacements and could be used for monitoring engineered slopes at a local scale. An essential factor for successful detection of low-magnitude displacements is the quality of control networks since control-related problems would inevitably cause a systematic error between multi-temporal datasets. In this study, a Leica total station with high accuracy and precision was used with care to create a robust control network and tie Leica targets to the local coordinate system based on the two fixed benchmarks on a nearby bridge. The quality of the geo-referencing was confirmed by the matching of the ribs on the carriageway in multi-temporal datasets. It is recommended that careful thought about the optimal control network for a given site is required before it is created. Measurements should be carried out carefully; for example, when a target is measured with a total station, the measurement can be repeated several times to obtain an average. However, in an outdoor environment, it is not always possible to find fixed objects in adjacent areas which can be used for geo-referencing. In such cases, a total station and prisms can be employed to create a local coordinate system based on fixed objects that are relatively far from the sites to be scanned. Alternatively, a competent Differential Global Positioning System (DGPS) can be considered for the creation of control network.

The MA with a grid size of 0.5m × 0.5m was used to create DEMs. The downside of the method and the parameter used was a reduction of spatial resolution, which might be important in some cases. However, in this application, such a resolution is acceptable because soil shrinkage should be fairly uniform over the area of concern. In addition, a greater grid size will reduce measurement errors and the effect caused by local surface variation.

Only two laser surveys were carried out. The slope movements measured by the TLS in this case unfortunately could not be verified by other means, such as extensometers. However, the matching of the raised ribs on the motorway in multi-temporal datasets and the variation of soil water content (figure 2) suggest that the slope movement was very likely to be shrinkage.

A major challenge for using TLS to monitor engineered slopes is associated with low vegetation due to data shadowing. In this study, the grass in the upper part of the slope was removed prior to scans being carried out. A detailed study on the effect of low vegetation on surface change detection is ongoing.

6. Conclusion

In high plasticity clays, the seasonal cycles of drying and wetting cause the soil to experience a volumetric change, resulting in soil shrink and swell. Vegetation contributes to the process through transpiration. This paper reported the successful use of TLS to detect small deformations caused by the shrinkage of a high-plasticity clay slope. The average shrinkage was about 10 to 15mm, which is the typical magnitude of displacements for such slopes due to seasonal drying. Geo-referencing is a critical aspect of successful projects involving surface displacement measurement with laser scanners. In this study, a very accurate control network was created using a high-accuracy total station, which was confirmed by the comparison between the raised ribs on the carriageway in the sequential laser survey data. The results demonstrate the potential of the technique for monitoring small displacements. Research is being carried out to investigate a number of practical issues associated with slope monitoring using TLS. The results will be reported in a future publication.

Acknowledgements

The authors would like to acknowledge funding for the project from the UK Engineering and Physical Sciences Research Council (EPSRC) under grant number EP/G056102/1.

References

[1] Smethurst J A, Clarke D and Powrie W 2006 Seasonal changes in pore water pressure in a grass-covered cut slope in London Clay *Geotechnique* **56(8)** 523-37

[2] Smethurst J A, Clarke D and Powrie W 2012 Factors controlling the seasonal variation in soil water content and pore water pressures within a lightly vegetated clay slope *Geotechnique* **62(5)** 429-446

[3] Ground Engineering 1996 In the limelight *Ground Engineering* (London: Thomas Telford) 26-27

[4] Kovacevic K, Potts D M and Vaughan P R 2001 Progressive failure in clay embankments due to seasonal climate changes *Proc. of the 5th Int. Conf. on Soil Mechanics and Geotechnical Engineering* (*Istanbul)* 2127-30

[5] Jaboyedoff M, Demers D, Locat J, Locat A, Locat P, Oppikofer T, Robitaille, D and Turmel D 2009 Use of terrestrial laser scanning for the characterization of retrogressive landslides in sensitive clay and rotational landslides in river banks *Can. Geotech. J.* **46(12)** 1379-90

Vezočnik R, Ambrožič T, Sterle O, Bilban G, Pfeifer N and Stopar B 2009 Use of terrestrial laser scanning technology for long term high precision deformation monitoring *Sensors* **9** 9873-95

Schürch P, Densmore A L, Rosser N J, Lim M and McArdell B W 2011 Detection of surface change in complex topography using terrestrial laser scanning: application to the Illgraben debris-flow channel *Earth Surf. Proc. Land.* **36** 1847–59

Wang G, Philips D, Joyce J and Rivera F O 2011 The integration of TLS and continuous GPS to study landslide deformation: a case study in Puerto Rico *J. Geodetic Sci.* **1(1)** 25-34

[6] Scott J, Loveridge F and O'Brien A S 2007 Influence of climate and vegetation on railway embankments *Proc. of the 14th European Conf. on Soil Mechanics and Geotechnical Engineering (Madrid)* vol 2 659-64