Deformation of Geogrid Reinforced River Bank using a Laser Scanner

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ABSTRACT: Geogrid reinforced structures (GRS) have been constructed and monitored since the 1980s, but deformation data for real industry case studies is often limited in scope, quality and quantity. With the recent advance of laser scanning technology, obtaining detailed deformation data, has become much more efficient, with the latest scanners capable of surveying thousands of individual measurements every second.

Laser scanning is unobtrusive, negating the need for targets attached to the face and indiscriminate, allowing analysis to be undertaken post-survey, saving time. The system is particularly suited to surveying horizontal deformation, during or after construction, as it can measure profiles of GRS to within a noise range of ±5 mm.

As part of infrastructure development on a former forge site, in the Kirkstall area of Leeds, to facilitate access to a new rail halt, new highways were proposed to the North and South banks of the River Aire together with a new road bridge. The embankments on both sides of the river were constructed with HUESKER Fortrac® T uniaxial high tenacity polyester geogrids, in combination with Allan Block segmental blocks. This project also utilised a new positive connection system, for connecting geogrid to block. The reinforced concrete bank seats, for the new stitch bridge, are supported on reinforced soil structures to the North and South of the river.

A terrestrial laser scanner was used to survey multiple stages of construction of the Northern section of the reinforced embankments, to determine any change in profile, due to the overlying layers and bridge deck. The most critical cross-sections were extracted from the virtual 3D model of the embankment, and detailed in the paper.

The paper starts with a brief introduction to GRS, before discussing how laser scanning is well suited to the surveying of horizontal deformation. The case study details are then outlined, along with the laser scanning results, showing small deformation levels, despite the high increased loading from the bridge, between scans. Finally, the last section discusses the success of the application of laser scanning for this project.

Keywords: Geogrid, Reinforcement, Design, Laser Scanning.

1 INTRODUCTION

Geogrid Reinforced Structures (GRS) are used as a solution to create retaining structures, where reinforcement prevents backfill from assuming its natural slope angle of repose, providing a potentially economically beneficial and more sustainable alternative to mass concrete and other retaining structures (WRAP, 2010). GRS typically consist of several key components (Figure 1): geogrid reinforcement; reinforced soil fill; retained backfill soil; foundation soil and can include a range of optional facing components, providing local support to the reinforced soil fill (e.g. segmental blocks, concrete panels, wraparound etc.).

As a result of the need to reduce the excessively conservative nature of commonly used GRS designs (Bathurst *et al*., 2002), monitoring of GRS structures has been widespread since they started to be increasingly used in the 1990's. Typically this has been undertaken using conventional geotechnical monitoring techniques such as strain gauges, inclinometers and assessing the face of the structure using conventional survey equipment.

Improvements in the scanning speed and mobility of Terrestrial Laser Scanners (TLS) enabled the successful implementation within geotechnical engineering. They have also been selectively used to monitor deformation in GRS (Scotland *et al.* 2014). There are many advantages of using this advanced form of surveying, not least their ability to measure large swathes of a structure in a short space of time, with minimal effort.

This paper presents the features of TLS and includes performance results of an innovative GRS as river embankments and an integrated abutment, near Leeds in the UK.

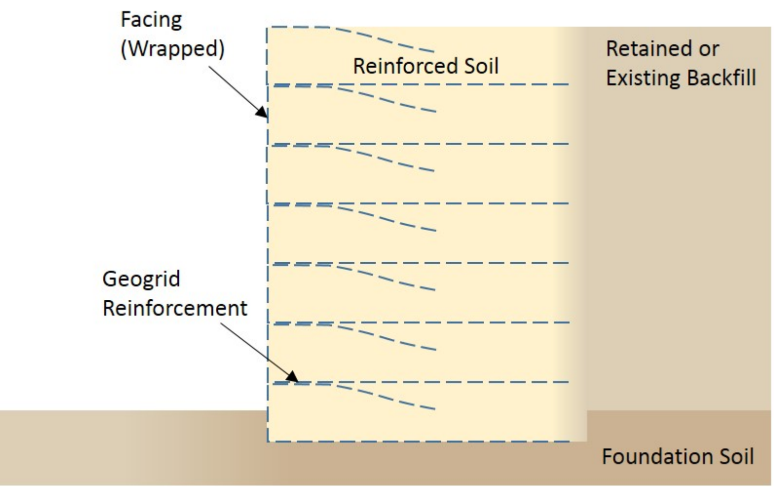

Figure 1: Typical Components in a GRSRS

2 LASER SCANNING IN GEOGRID REINFORCED STRUCTURES

This study presents a TLS, which is a form of surveying to monitor the face profile of two individual GRS. The advantage of profiling the face is that the data measured is the maximum movement acting through the structure, as it is a combination of face deformation, internal deformation and external deformation. Monitoring structures in this way, makes it difficult to differentiate the source of the deformation. However both GRS case studies featured in the report were monitored only in the medium-term (< 6 months), where the face deformation mechanism was expected to be the critical mechanism contributing to deformation observed.

A TLS is essentially an advanced form of a total station. Whereas a total station projects a single beam at a target using a phase shifted laser, a TLS uses a rotating mirror at high speed and moves automatically over a set grid. This allows the device to scan a large field of view in a short time space, with minimal effort from the operator. Modern TLSs also contain on-board data loggers, human interfaces and on-board cameras, for ease of use and for post-processing visualisation.

Similarly to total stations, the TLS featured in this paper uses a time of flight laser scanner, where the distance to an object is calculated based on the time it takes for the pulse of light to reflect off an object and back to the scanner. The on-board computer logs its position in 3D space relative to the scanner. As it does this for the whole structure, it builds up a 3D representation of this data, termed a point cloud. This point cloud essentially contains thousands of individual coordinates equivalent to those obtained using total station surveys.

TLS have been successfully used to monitor deformation in GRS before (Scotland *et al.* 2014). The authors undertook scans at three periods during construction and used *Excel* and *Cloud Compare* to extract profile deformation data for comparison.

2.1 *TLS Equipment*

The laser scanner used in this assessment was Leica's Scanstation P40 (see Figure 2). A previous study by Mechelke et al. (2007) found an older version of this TLS to have a noise range of ±5 mm at a distance of 20 m. This level of accuracy is acceptable for the level of GRS deformation expected (>10 mm) by a typical wrapped faced GRS (Duijnen et al., 2012).

As with other surveying devices, accuracy and repeatability are dependent on a number of external factors such as weather, tampering and most importantly reliable control points, which are outside the area of influence of the engineering structure. High definition scanner (HDS) targets were chosen to locate these control points, as Kersten et al. (2008) had shown them to be more accurate (±3 mm) for the laser scanner, than black and white (±5 mm) or spheres targets (±5mm), over a distance of less than 50 m.

Figure 2. Typical Laser Scanning Equipment

3 GEOGRID REINFROCED BRIDGE ABUTMNET

3.1 *Problem – Site History and Proposed redevelopment*

The monitored GRS was situated on the redevelopment of a former forge site, in the Kirkstall area of Leeds which will eventually include a combination of residential, commercial and leisure facilities, as well as a new rail halt and a road bridge over the River Aire. The river bisects the site approximately East to West. In order to facilitate the construction of the new structures and rail halt, a new bridge had to be installed, along with significant regrading of the site, above flood level.

Prior to its redevelopment by Commercial Estates Group, the site was home was used for iron production which was developed in around 1580. Prior to this the Cistercian monks of Kirkstall Abbey had used the site as a mill, dating back to the 12th century (Butler 1954). The site became derelict in the 2002, when the facility closed and work moved over seas. It has remained unused until its redevelopment. The pre-existing banks of the river consisted of a combination of brick platforms, king post walls and natural slopes, which had to be removed and raised to the proposed higher level. Figure 3 shows the typical condition of the river banks prior to construction.

Figure 3: The Kirkstall Forge site before construction

3.2 *Solution*

A number of earth retaining options were considered by the main consultant, WYG, including permanent sheet piles, however the final decision was to utilise a combination of geogrid reinforced slopes and walls in order to meet the aesthetic requirements of the project. The reinforced embankments were designed by specialist consultant PaSCoE to BS 8006-1 (British Standards Institute 2010), utilising HUESKER's Fortrac® T uniaxial high tenacity polyester geogrids, in combination with Allan Block segmental facing blocks. The combined riverbank, was up to 8.55 m high.

For the Southern and Northern underlying reinforced slope, HUESKER's GRS Fortrac Natur system was used at an inclination of 60°. Stability analysis of the Northern embankment's underlying reinforced slope required up to 7 wrapped layers of geogrid, spaced at 0.4 m (Figure 5). Two grades of polyester (PET) geogrid layers were used, with short-term tensile strengths of 35 kN/m and 55 kN/m. A fine geomesh, HaTe 23.142 was installed behind the wrapped face of the slope to prevent wash out of the backfill.

Overlying the Northern slope was a reinforced soil retaining wall, utilising segmental block walls reinforced with up to 12 geogrid layers, with strengths of 35 kN/m and 55 kN/m. This project also utilised a new positive connection system, for securing the geogrid to block, by means of wrapping the geogrid around a PVC bar, which runs along a notch in the segmental block.

In the abutment section of the embankment, reinforced concrete bank seats were cast in situ over the reinforced slope, to house the new 30 m long stitch bridge, were supported on the reinforced slopes to the North and South of the river.

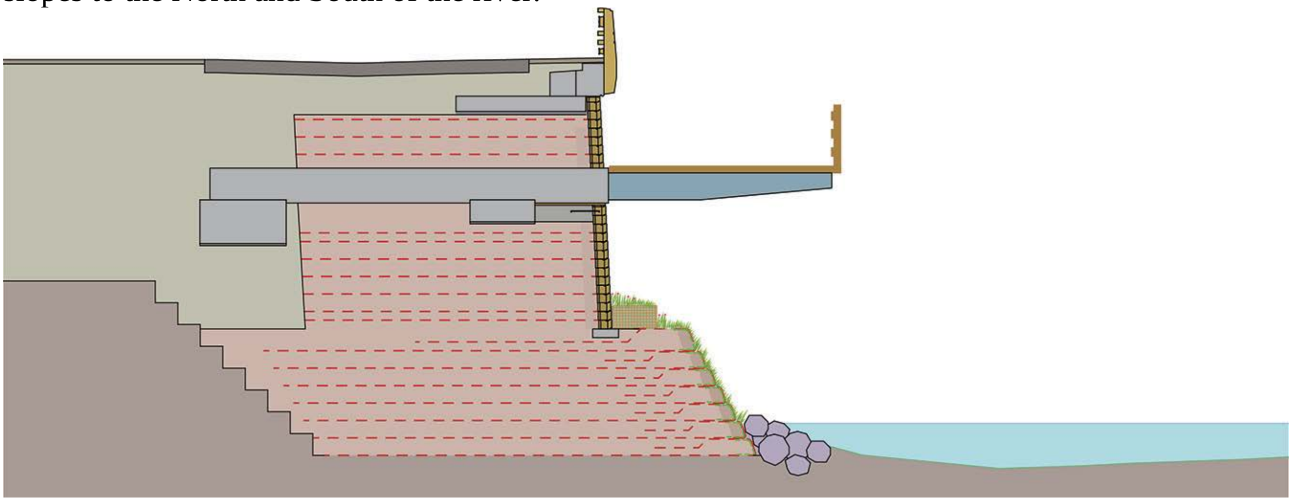

Figure 4. Typical Arrangement of GRS on Northern Embankment

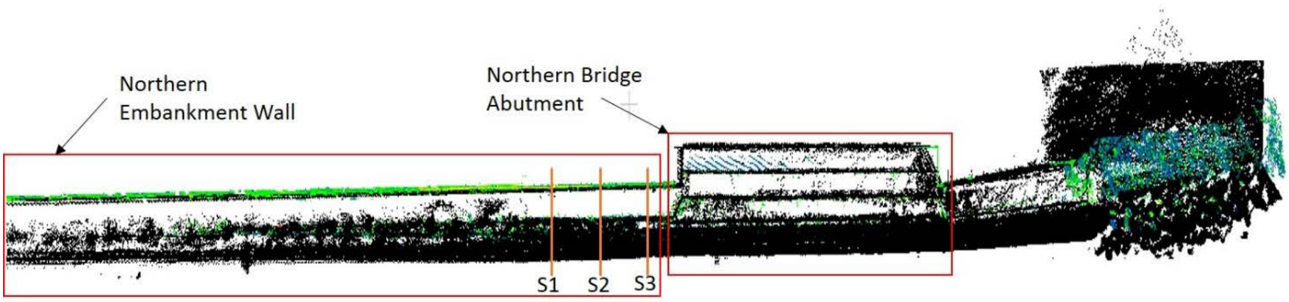

Figure 5. Plan of GRS on Northern Embankment

3.3 *Construction and Scanning Programme.*

The main earthworks contractor I&H Brown, subcontracted the construction of the reinforced embankments to specialist Thomas Ben. Construction of the Northern embankment started in April 2015, with the installation of a cofferdam, to enable construction below the normal river level. The reinforced slope was constructed in layers behind a moving formwork set to the desired inclination. The Northern cofferdam was removed upon reaching a safe height above the flood level.

At this point in the programme, construction of the reinforced retaining wall and Southern reinforced slope began. Once above the safe river level on the Southern embankment, the cofferdam was removed, allowing, the first laser scan to be undertaken of a 100 m stretch of the Northern embankment. By 11th August 2015, the bridge seats had just been poured and the neighbouring reinforced wall had reached half height (Figure 6).


Figure 6: Construction of Northern Embankment in August 2015 and first laser scan (top left)

In the month following, the bridge deck beams (approx. 100 tonnes) were lifted into place on their bank seats, and the embankments on both sides of the river reached their final heights. The authors took this opportunity to undertake a second laser scan of the Northern embankment on 10th September 2015. The scan was undertaken from the South embankment, containing over 5 million individual readings.

3.4 *Flooding and Further Laser Scanning*

Following the completion of the reinforced slope and walls, the bridge deck was cast and was nearing completion when on the 25th and 26th December 2015, the UK experienced an extreme rainfall event. The North of England in particular was affected, with an average of 65 mm of rainfall falling in the catchment area of the River Aire, during the two days (Figure 7; Met Office 2016). This figure illustrates the extreme nature of this rainfall in comparison to the month leading up to and following the event. This led to the river reaching its highest recorded level (40.1 m OD) on 26th December 2015. Apart from some topsoil washout, observed damage was minimal on both river banks. However elsewhere on the 114 km long river, the river broke its banks, causing flooding (BBC 2016). A photo (Figure 8) taken the following day, illustrates the extreme level of the river.

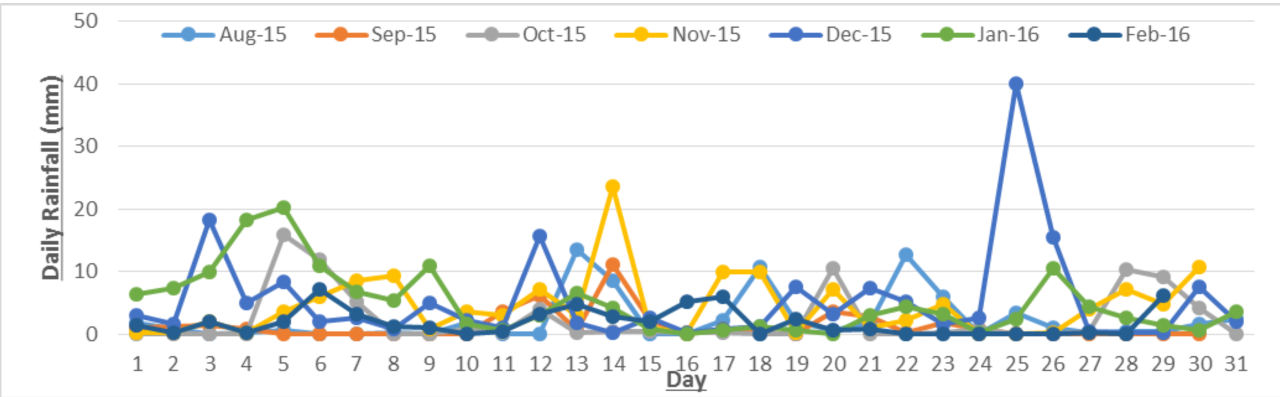

Figure 7: Daily rainfall data for North East England, August 2015 to February 2016 (Met Office 2016).

Figure 8: Condition of the River Aire on the 27th December 2015

When the storm had subsided and the site was accessible again, the authors surveyed the site on the 4th February, to observe any potential movements caused by the flooding and high water level.

3.5 *Deformation Performance*

The point clouds of all three scans were extracted to *Cloud Compare*, where they were registered and aligned using control points. The difference between point clouds is highlighted as deformation. Figure 9 presents a comparison between the first and second laser scans of the Northern embankment. Deformation is highlighted as blue (low) to yellow (high). The comparison shows little change (<20 mm) for most of the river bank. There are intense pockets of change reported, but these are due to vegetation growth, or the completion of the wall and bank seat.

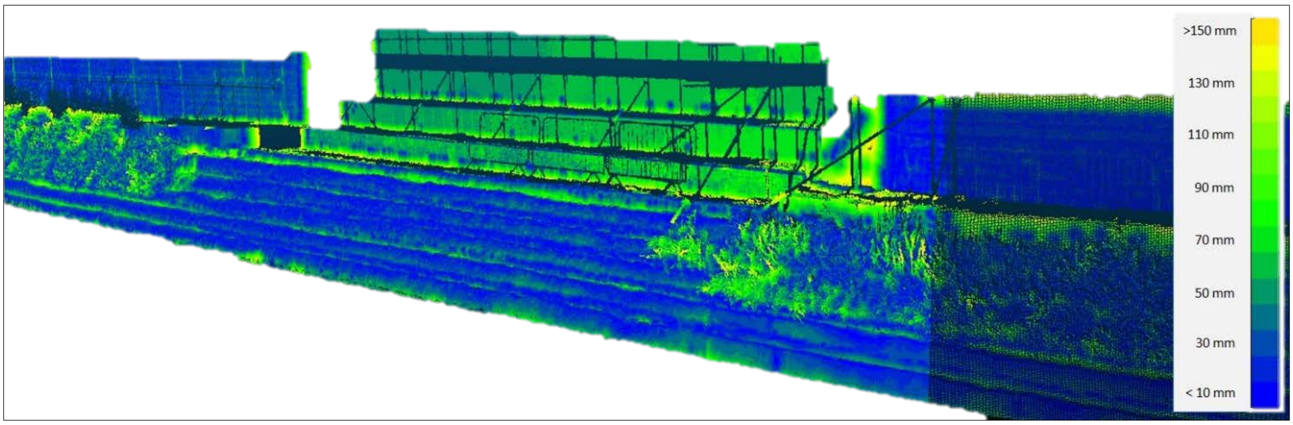

Figure 9: Deformation between laser scans before (10/09/15) and after flood event (04/02/16)

In order to analyse deformation, the point cloud of the Northern river bank was sliced into 3 cross sections, 5 m apart (S1. S2 and S3 in Figure 5). The authors systematically selected these cross-sections through the underlying slope, using a feature in Cloud compare called “*Profiling*”. This generates a best fit line for the points in the cross section (Figure 10). Although this best fit line cause small errors, due to the profile approximation algorithm, it can be used to evaluate the shape of the wrapped face slope along the river bank. Figure 10 shows low levels of deformation (<30 mm) on the wrapped faces. It also highlights, the spatial variation in shape of the reinforced slope along the embankment from upstream (left) to downstream (right), which is not always picked up by traditional surveying techniques.

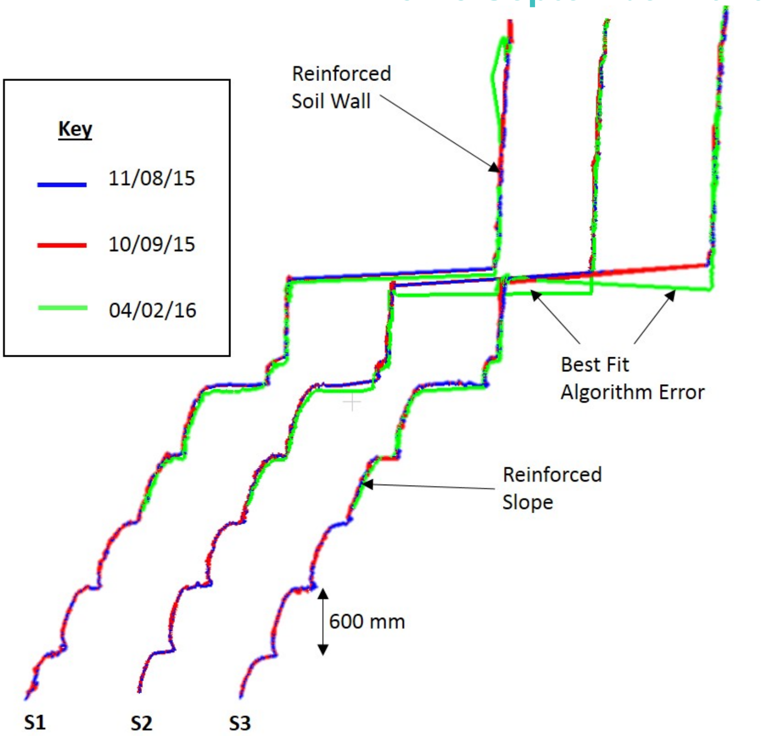

Figure 10: Cross Section comparison from three stages of monitoring

4 DISCUSSIONS

Although TLS are not as accurate as other surveying devices such as total stations (Bussert 2012), they enable the monitoring of the large areas of embankments. As they are line of sight measuring devices, the TLS cannot scan underwater. High river levels also prevent the lowest layers from being scanned. Likewise, the growth of vegetation between the scans, prevents the whole slope from being recorded.

5 CONCLUSION

This paper summarises the development of a geogrid reinforced river bank which includes the combined use of reinforced steep slopes and a segmental block wall. The use of high strength geogrid, combined with a recycled aggregate was used to create reinforced embankments.
The performance of the Northern river bank was monitored over a 6 month period using a terrestrial laser scanner, which have been shown to be an effective monitoring device of geogrid reinforced structures. During the surveying period, the riverside embankment was subject to an extreme rainfall event, causing the river to reach record levels. Aside from some washout of topsoil, the reinforced embankment showed no significant damage or deformation, proving GRS resilience to extreme weather events.

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