APPLICATION OF SURVEYING TECHNIQUES FOR MONITORING AND APPRAISAL OF EXCAVATED CHINA CLAY SLOPES

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Abstract

The recent introduction of the Quarries Regulations 1999, within the United Kingdom, has emphasised the need for a preliminary hazard appraisal, prior to undertaking a more detailed geotechnical assessment of slopes considered to represent a significant hazard. Hazard appraisal should differentiate between slopes requiring further investigation and those that do not pose a significant hazard. Both slope geometry (height and angle related to rock quality) and whether or not any potential instability may result in harm to persons or property are used to define what is meant by significant hazard. Data obtained from several surveying techniques, including GPS, remote laser profiling and a total station using a fixed target system, is being used for monitoring and preliminary hazard appraisal of excavated china clay slopes. Topographic data, measured using a GPS surveying system, has been used to create digital terrain models of clay pits operated by IMERYS Minerals Limited, St Austell, United Kingdom. Data manipulation within the recently developed DATAMINE mine design system STUDIO, has allowed sections of slopes that are defined as significant from a geometrical viewpoint to be identified. Use of this technique is enabling the required preliminary hazard appraisal of excavated slopes operated by IMERYS to be undertaken effectively and efficiently.

Conventional use of the Quarryman ALS remote laser-based profiling system, within the china clay industry, is used to provide the necessary quarry slope geometry/profile information prior to undertaking blast design. The same system has also been used to assist characterisation of the failure scar of a recent discontinuity controlled flowslide that occurred in an excavated china clay slope. Results from periodic profiling, using the remote laser-based system, show that the technique provides useful information for both monitoring and quantification of slope regression. The laser-based system has also been used to complement more conventional precise slope deformation monitoring using a total station and fixed target system for a critical excavated slope. The techniques described within the paper represent novel applications to the United Kingdom extractive industries and will be of considerable assistance in slope engineering and landslide management.

1. Introduction

The use of several surveying techniques including GPS, remote laser profiling and a total station using a fixed target system form part of operational activities within china clay excavations operated by IMERYS Minerals Limited in the south west of the United Kingdom. The surveying techniques are used to provide essential spatial data to produce production plans, undertake initial hazard appraisal of excavated slopes, perform slope face geometry profiling and provide spatial data for blast design purposes and monitor slope stability of identified critical excavations. The paper reviews each application with reference to a typical china clay pit. A summary of the surveying techniques used by IMERYS is provided in Table 1.

In the United Kingdom IMERYS currently operate thirteen open pits in Cornwall and three in Devon. The total volume of sales for the operation for 1999 was 2.6 million tonnes at 10%

equivalent moisture content. 75% of the product was sold into the Pigments and Additives market, 23% into the Ceramics and Speciality market and 2% into the Refractories market. The quality of the china clay mined and processed is a function of the mineralogy and chemistry of the parent granite, together with the intensity and extent of hydrothermal mineralisation and subsequent kaolinisation. In general, the more intense the kaolinisation the better the quality from a commercial viewpoint.

EQUIPMENT	ACCURACY	APPLICATION
Leica T2000 DI4L Distoplate	± 5mm	Fixed-target quarterly monitoring of identified critical slope.
GPS Spectra Precision Single and Dual frequency	± 12mm in x, y and z Real Time Kinetic	Survey location of crest and toe of slopes. Survey records in National Grid coordinates.
ALS Quarryman Reflectorless mode	5cm over 300m	Slope face profiling for blast design. Remote profiling of slope geometry.

Table No. 1 Summary of surveying techniques used by IMERYS

The intensity of kaolinisation (extent of weathering/hydrothermal alteration of granite) also dictates/controls the engineering behaviour of excavated china clay slopes. In order to undertake pit slope hazard appraisal it is important, therefore, to establish the spatial location of varying alteration and determine accurate slope dimensions/geometry (slope height, slope angle).

2. Slope monitoring

Regular slope monitoring of a critical section of an open pit has been undertaken since 1992. Figure 1 shows images of the western face of the monitored slope. An aerial view of the china clay pit is provided in Figure 2. The pit is currently 90m deep; elliptical in shape (900m long and 700m wide) with the long axis aligned north. The western slope contains highly kaolinised granite and has an overall slope angle of 26 degrees. Individual benches are 15m high, 12 m wide and have a bench slope angle of 40 degrees.

Small-scale instability on upper bench

Lower section of the western face – looking in a northerly direction

Figure No. 1 Images of western face where regular slope monitoring is carried

Under the Quarries Regulations the western slope of the china clay pit poses a significant hazard in view of the proximity of a public road and buildings adjacent to the slope crest. The monitoring programme, consisting of dual-height casagrande piezometers and fixed targets, was instigated as part of a detailed geotechnical assessment of the western slope (Pine *et al*. 1994). Quarterly reading of the fixed targets have been taken since installation in 1992 using a Leica T2000 and electronic distance measuring system (EDM) semi-total station. 13 fixed targets are positioned at several locations on the slope (crest, upper and lower benches with lateral coverage). Within the overall accuracy of the measurements (± 5mm) there has been no detectable movement relating to overall slope instability. Seasonal fluctuation has been detected; with expansion in the winter and contraction in the summer. Results from the regular monitoring provide confidence in the design factor of safety for the excavated slope. Small-scale heaving has occurred on several benches, such as that shown in Figure 1, but this appears to be isolated and controlled by structure (greisen veining).

Grainger and Kalaugher (1996) using photographic techniques have also monitored the small-scale instability observed on the western slope. The optical monitoring instrument incorporated a single-lens reflex camera (Nikon F3) compatible with a standard tribrach, with optical plummet, for mounting on a surveying tripod.

3. Hazard appraisal of excavated slopes

3.1 Characterisation of Excavated Slopes in Kaolinised Granite

Several researchers, including Irfan and Dearman (1978), Baynes and Dearman (1978), Hencher *et al.* (1990) and Stead *et al.* (2000), have highlighted the varying engineering properties associated with the hydrothermally altered granites of the south west of England. Characterisation of weathered or altered rock usually involves categorisation into classes, zones or grades according to readily recognised or simply measured changes in their characteristics which are perceived to indicate significant changes in engineering behaviour. The Geological Society Engineering Group Working Party (Anon 1995) provided guidelines for the description and classification of weathered rocks. Table 2 summarises the key features for characterisation of excavated slopes in kaolinised granite.

GRADE	DESCRIPTION	CHARACTERISTICS
I	Fresh Rock	No visible alteration. Requires many hammer blows
II	Slightly Altered	Slight discolouration and weakening. Schmidt Hammer 'N' > 45. More than one hammer blow to break.
III	Moderately Altered	Considerable weakening. Penetrative discolouration. Single hammer blow breaks rock. Schmidt hammer 'N' 25-45.
IV	Highly Altered	Large pieces broken by hand. Schmidt hammer 'N' 0-25.
V	Completely Altered	Considerably weakened. Geological Pick penetrates. Original texture preserved. Slakes readily in water. Hand penetrometer 50-250 kPa
VI	Residual Soil	Soil mixture with no rock texture. Penetrometer < 50 kPa

Table No. 2 Characterisation of weathering/alteration grades (modified after Anon 1995)

Based on the principles outlined, alteration grades or classes can be assigned to specific slopes or sections of slopes within an open pit. In addition, geotechnical mapping is undertaken to determine the influence of discontinuities present within a slope.

The kaolinisation intensity or weathering grade/class not only influences the engineering behaviour of any slope but also dictates whether granite can be mined hydraulically using high pressure (20bar) water cannons know as monitors, whether it has to be ripped using bull-dozers prior to hydraulic mining or whether it has to be drilled and blasted before loading and hauling to tip as waste.

3.2 Hazard Appraisal

The recent introduction of the Quarries Regulations 1999 within the United Kingdom has emphasised the need for a preliminary hazard appraisal, prior to undertaking a more detailed geotechnical assessment of slopes considered to represent a significant hazard. Both slope geometry (height and angle related to rock quality) and whether or not any potential instability may result in harm to persons or property are used to define what is meant by significant hazard.

The Regulations indicate the hazard should be significant if:

a) in the case of moderately weak or stronger rock
    i) the vertical height of any individual face is more than 15m; or
    ii) the overall vertical height of any adequately benched face or slope, measured from toe to crest, is between 15 and 30m, and the overall face angle is steeper than 1 horizontal to 1 vertical.

b) in the case of weak or very weak rocks and engineering soils, where the vertical height of any part of the excavation is more than 7.5m, and the overall face angle is steeper than 2 horizontal to 1 vertical (27 degrees to the horizontal).

The approach adopted at IMERYS, in view of the extensive number of slopes involved, has been to establish a system that allows effective and efficient preliminary hazard appraisal. Topographic field survey data, measured using a GPS surveying system, has been used to create digital terrain models of clay pits. Two GPS systems are used by IMERYS, both are manufactured by Spectra Precision: Dual frequency model No. GTR3220 and Single frequency model No. GTR3140. All surveys are based on the National Grid. With the advent of GPS all stations are derived in Cornwall from the OS Trig pillar (primary) at Hensbarrow at the centre of the china clay mining district. All stations are established by RTK (real time kinetic) methods. At the periphery of the area the z value is checked against known bench marks. The instrument records in National Grid co-ordinates that are adjusted for curvature, scale factor and height above sea level.

Data manipulation within the recently developed DATAMINE mine design system STUDIO, has allowed all slopes that are defined as significant from a geometrical viewpoint to be identified. The system calculates the dip and dip direction of every triangle (the actual dimensions of which are a function of specified contour interval, but are typically 5m) within the digital terrain model. Filtering of the data is then performed to target slopes greater than a specified critical angle. A string is then wrapped around each set of triangles that represent an individual slope. The strings are then assigned individual numbers and for each slope the height, average dip; minimum and maximum dip together with standard deviation, and the average direction of the dip of the slope is calculated. Each string (slope) is then assigned a weathering/alteration grade/class.

Figure 3 shows a plan view of an example digital terrain model of the operational pit including key surface topographical features and elevation contours at 2m intervals. Following the methodology described the data is then filtered to eliminate slope elements below a specified angle. Figure 4 shows an image from the filtered digital terrain model highlighting specified slope elements with superimposed weathering grade. Figure 5 provides a three-dimensional block-model image of the western section of the china clay pit. From analysis of the digital terrain data, based on slope height and slope angle for a specific weathering class, it is then possible to determine whether or not the slope represents a significant hazard from a geometrical viewpoint.

Figure No. 2 Aerial view of china clay pit (western face on left-hand side of image)

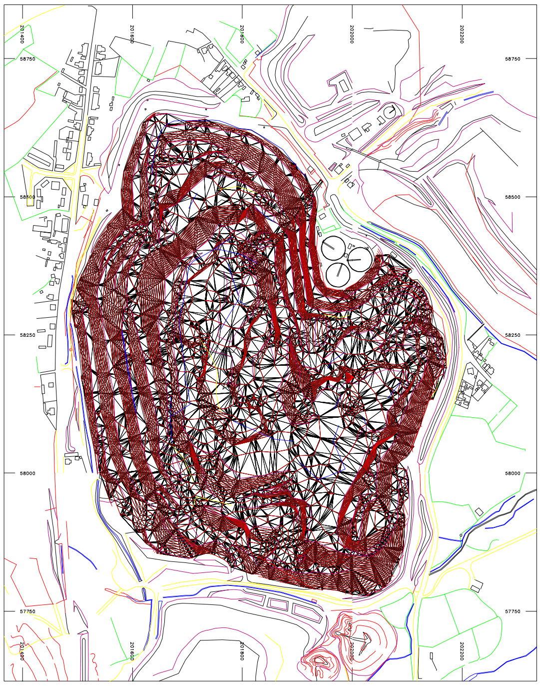

Figure No. 3 Digital terrain model (including surface topography)

Figure No. 4 Digital terrain model of slope elements with superimposed weathering class.

Figure No. 5 Three-dimensional block model of the china clay pit

Additional factors, such as location of personnel, proximity of public access, buildings etc are then combined with the geometrical data to determine whether or not a more detailed geotechnical assessment of the slope is necessary. Use of this technique has enabled the required preliminary hazard appraisal of excavated slopes operated by Imerys to be undertaken effectively and efficiently. Processing of the information also allows prioritisation of the perceived hazard for implementation of the required geotechnical assessments.

4. Slope face profiling

4.1 Conventional face profiling

Conventional use of the Quarryman ALS motorised remote laser-based profiling system (Measurement Devices Ltd, 1998), within the china clay industry, is to provide the necessary slope geometry/profile information prior to undertaking blast design. The data is then used within Face 3D software (Measurement Devices Ltd, 1998) to prepare a blast design and assess the potential impact of borehole spacing, burden, subgrade drilling etc. The interactive software allows full editing and provides true burden and shothole reporting in three dimensions. Figure 6 provides a typical image of an operational china clay slope face from data captured using the profiling system. The introduction of such a system has improved overall blast design efficiency within the china clay operations.

4.2 Profiling of slope failure

The Quarryman ALS system has also been used to assist characterisation of the failure scar of a recent discontinuity controlled flowslide that occurred in an excavated china clay slope. The slope failure occurred on 31/10/98 following a period of prolonged rainfall and was associated with a 50m high slope that had an overall slope angle of 40 degrees. The overall slope contained a mixture of china clay matrix and sections of relatively unkaolinised granite. Further details of the back-analysis of the failure can be found in Coggan *et al.* (2000). Figure 7 provides a recent image of the failed slope. In view of difficulties with access the remote laser-based system proved extremely useful in providing geometrical data relating to the failure. The accuracy of the device (5cm over 300m in reflectorless mode) was considered sufficient for the application.

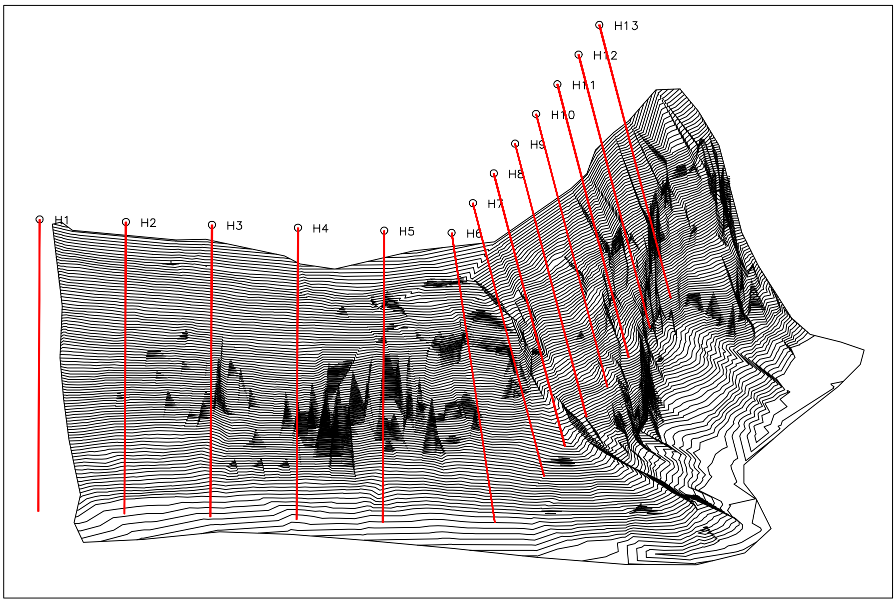

Figure No. 6 Image of typical china clay slope face generated from laser profiling.

Generation of a three-dimensional image of the upper region of the slope failure was performed after importing the recorded x-y-z slope surface data from the Quarryman ALS into the DATAMINE system. Figure 8 provides a profiled image of the upper region of the failure scar. The quality of the image generated clearly demonstrated the controlling influence of discontinuity orientation on the failure process and allowed improved visualisation and enhanced characterisation of the failed slope surface. Use of the Graphics Visualisation Package (GVP) contained within the modular DATAMINE system allowed true three-dimensional visualisation of the data to exact dimensions and spatial position. The interactive package also allowed the user to change view orientation and zoom in and out to examine specific spatial relationships in detail.

Figure No. 7 Photographic image of slope failure scar looking in an easterly direction.

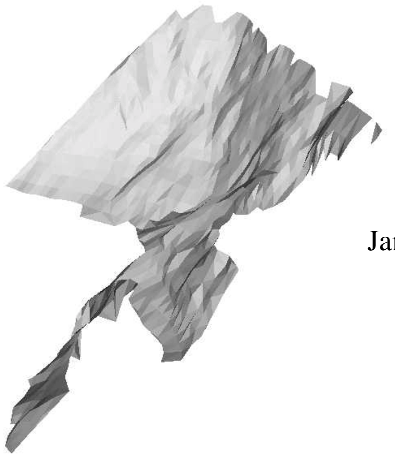

Figure No. 8 Profiled three-dimensional image of upper region of failure scar.

Using a similar methodology periodic profiling has been used to both visualise and quantify slope regression. Figure 9 shows images of slope regression generated from two laser profiles; the first taken after slope failure during January 1999 (lighter profile) and the other in August 1999 (darker profile). Wire frame models were created for GPS survey data of the slope prior to failure and the two laser-profiles undertaken following failure. Differences between the two laser-profiles were used to generate a block model within the GVP software for visualising and volumetric calculation of the intervening regression. This technique was used to determine both failure regression (using wire-frames generated from GPS survey data of the slope face prior to failure and profiling data following failure (January 1999)) and periodic regression (utilising profiling data from January 1999 and August 1999) for the upper region of the failure scar. Failure regression for the upper region of the failure was determined as 17,300m^3. Periodic regression was calculated as 1,094m^3. From Figure 9 it can be observed that the majority of the periodic regression during the period January-August 1999 was associated with sidewall collapse of the northern edge of the failure scar. Only minor retreat of the crest of the failure scar occurred during the same time period. Figure 10 provides superimposed scaled-sections taken through the wire frame models for the respective profiles.

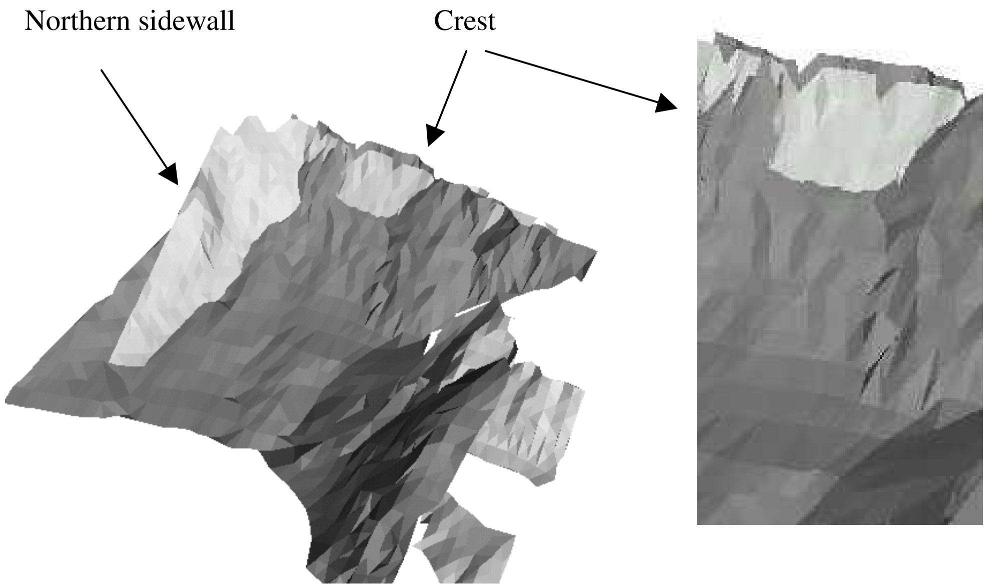

Figure No. 9 Combined profiled images for the period January-August 1999

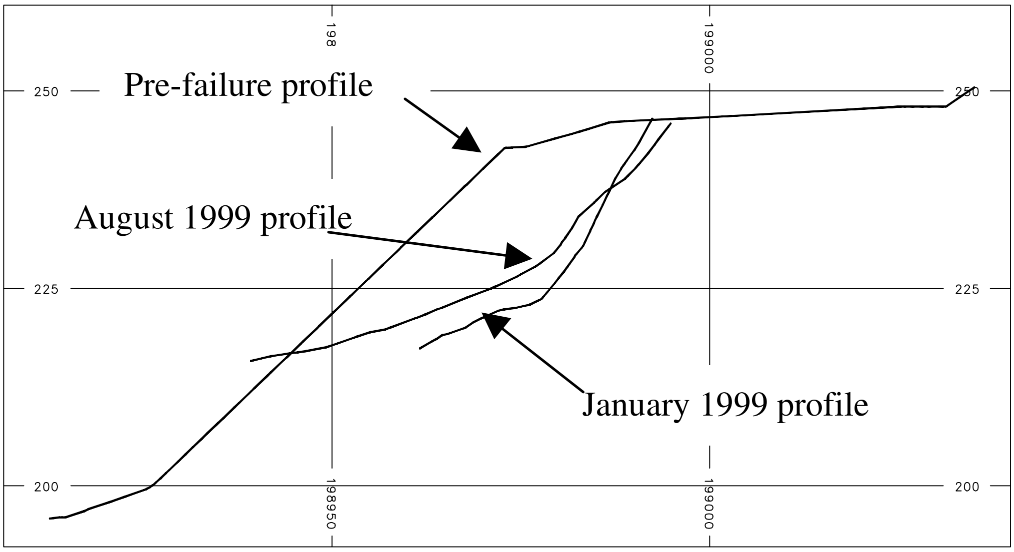

Figure No. 10 Cross-sections taken through respective wire frame models.

The remote laser-based system has also been used to complement the more conventional precise slope deformation monitoring system, described in section 2; by providing additional visualisation of the minor small-scale heaving observed on several benches of the western slope of the china clay pit shown in Figures 1 and 2.

5. Conclusions

In addition to providing information for production planning, surveying techniques have been used to provide essential spatial data for both monitoring of critical of slopes and preliminary hazard appraisal of excavated china clay slopes for compliance with recently introduced legislation.

The DATAMINE system STUDIO has allowed efficient and effective processing of geometrical data. The system has been used to provide spatial correlation between slope geometry and assigned weathering grade. When combined with analysis of additional factors such as location of personnel, proximity of access, buildings etc the system provides the necessary information to make decisions concerning the need for further more detailed geotechnical assessment according to the recently introduced Quarries Regulations.

Remote laser-based profiling has been used to assist characterisation of a slope failure scar by importing the generated x-y-z data into the mine design software DATAMINE. Utilisation of graphics visualisation software within DATAMINE has allowed detailed interrogation of the spatial data in three dimensions. The combined profiling data capture system and data manipulation capabilities of the mine design software provide a useful remote technique for visualisation and quantification of slope regression. The technique could have more widespread application in engineering slope/landslide management.

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