GEOTECHNICAL COURSE DATES:

Rock Description Workshop
27th Nov. 2014

In Situ Testing
18th November 2014

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30th October 2014

GEOTECHNICAL COURSE DATES:

Geotechnical Foundation Design - 6th November 2014

Soil Description Workshop
31st October 2014
4th Dec' 2014

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October 2014 | Issue 34

Investigating instability

Slope stability investigation at Barton on Sea continued

Natural gamma logging

The benefits of using wire-line logging tools

Pipe and tunnel investigation

The third article from Arrow Geophysics

Adaptive oedometer automation

What advantages can be obtained?

Contents

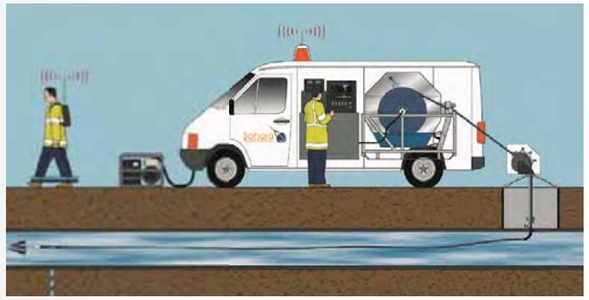
Welcome

Welcome to the 34th Edition of **theGeotechnica** - the UK's fastest growing online geotechnically focussed e-magazine.

This month, once again, we have a fantastic line-up of insightful and informative articles that make for a must-read.

The first article of this month's issue comes from Kim Beesley, Managing Director of European Geophysical Services, a multi-disciplinary team of Geophysics, geologists and geologging engineers providing a comprehensive wire-line service for borehole geophysical logging and video surveying. In this article Kim discusses how wire-line logging tools can be used to measure physical parameters down boreholes.

Writing our second article of this month's issue are Martyn Brocklesby and Elizabeth Withington, Director and Senior Manager at Geotechnical Engineering. Last month Pete Reading provided details of the recent survey works carried out on the English South Coast focussing on cliff instability. This month's featured cover article sees Martyn and Liz provide a perspective on Geotechnical Engineering's ground investigation work carried out on the affected area at Barton on Sea.



The third article is the second in a series of articles on geophysics from Arrow Geophysics Limited, a geophysical consultancy established in 2004 that provides advice on geophysical risk reduction for UK construction projects. This month's article is penned by Geoff Acland who this month Geoff explains the development of a specific technique for locating and investigating pipelines and tunnels at depth.

Our final article this month we have Dr Sean Rees of GDS Instruments writing the first in a series of articles for us. This month's offering sees Dr Rees discuss the automation of oedometer testing and determination of the end of primary consolidation

As with every new edition of the magazine, the Editorial Team here at **theGeotechnica** will be on the lookout for even more new, original and interesting content from all corners of the sector, and would actively encourage all readers to come forward with any appropriate and relevant content - whether it be a small news item or a detailed case study of works recently completed or being undertaken. If this content is media rich and interactive, then all the better. We are looking to increase the already large readership of the magazine through better social media integration and promotion, as well as improving content month on month.

Finally, for any content that is submitted we will ensure that an advertising space, proportionate to the quality of content provided, is reserved should you wish to place an advert in that single edition of the magazine. We hope you enjoy this month's edition of the magazine and are inspired to contribute your own content for the coming editions of **theGeotechnica**.

Editorial Team,
theGeotechnica

NATURAL GAMMA LOGGING

*Writing for **theGeotechnica** this month is Kim Beesley, Managing Director of European Geophysical Services, a multi-disciplinary team of Geophysics, geologists and geologging engineers providing a comprehensive wire-line service for borehole geophysical logging and video surveying. In this article Kim discusses how wire-line logging tools can be used to measure physical parameters down boreholes.*

Wire–line logging tools can measure a wide variety of physical parameters down boreholes. One of the most common and useful logs is natural gamma.

"The tool measures the naturally occurring gamma radiation found in rocks and sediments. It is mainly used to detect the clays that contain potassium K40…"

The tool measures the naturally occurring gamma radiation found in rocks and sediments. It is mainly used to detect the clays that contain potassium K40, though the Uranium U238 series of elements and the Thorium Th232 series of elements also emit gamma radiation – see Table 1. The higher the concentration of these clay minerals the greater the responses on the natural gamma log - see Figure1.

The natural gamma log is the most useful in sedimentary sequences in characterising the rock and identifying formation type and boundaries. The log should be used in conjunction with available geological data from the site to fine tune the final geological log especially where depth errors can occur when relying on cutting returns (lag) or there is poor core recovery.

The gamma log is often and easily run in combination with other geophysical logs thus saving time but also providing reassuring lithological control on each logging run.

"Clay affects permeability so identifying clay content is particularly useful in many situations…"

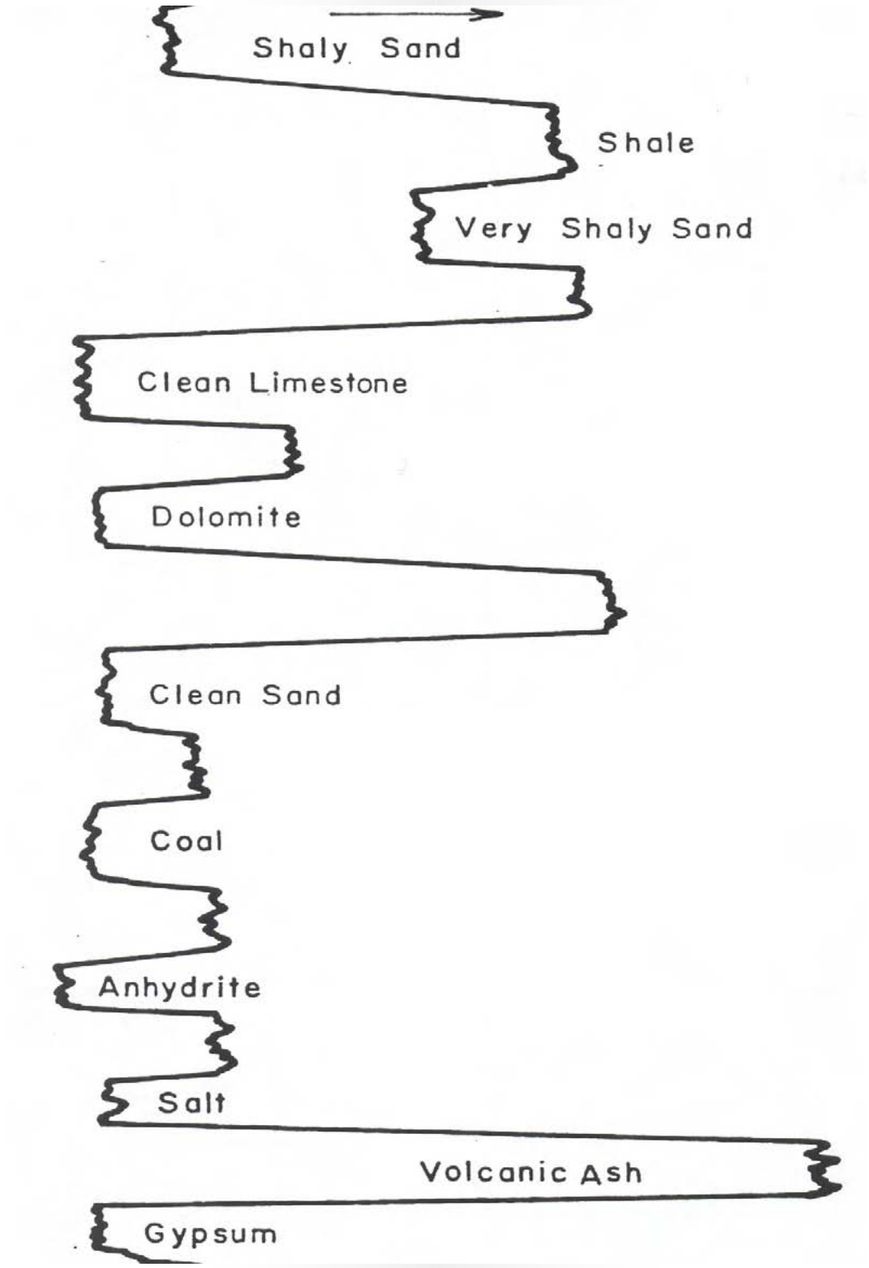


Figure 1. Natural Gamma responses (relative) for common rocks

Formation	Uranium	Thorium	Potassium K40
Shales Clays	1.2	10.1	324
Clean Sand	1.2	6.1	132
Carbonates	1.3	1.1	32

Table 1. Isotope content of common rocks (g / tonne)

Clay affects permeability so identifying clay content is particularly useful in many situations such as: water well design, groundwater monitoring installations, engineering designs and mineral extraction. So for a given situation where 100% clay gamma response (GR max) and zero or low clay gamma response (GR min) can be determined the gamma log response (GR) may be converted to volume of clay using the following the formula:

$$\text{Volume of clay} = \frac{\text{GR} - \text{GR min}}{\text{GR max} - \text{GR min}}$$

A typical response to clay is shown in Figure 2.

Natural gamma in combination with Gamma – Gamma (Density) LS and HR are easily run through a narrow diameter (typically 50 - 90mm diameter) single casing strings to identify coal beds and to determine

"Not only is this suite commonly used for coal exploration but also site investigations in coal mining areas…"

coal bed thickness. Not only is this suite commonly used for coal exploration but also site investigations in coal mining areas to identify coals, old workings and obtain detailed lithological information. Good quality coals have a low natural gamma response

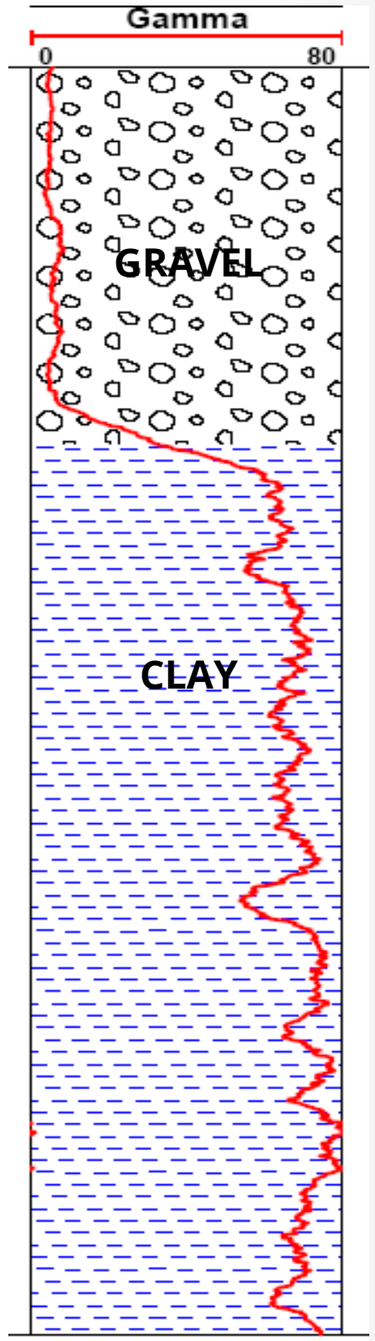


Figure 2. Natural Gamma response to clay free gravel overlying clay

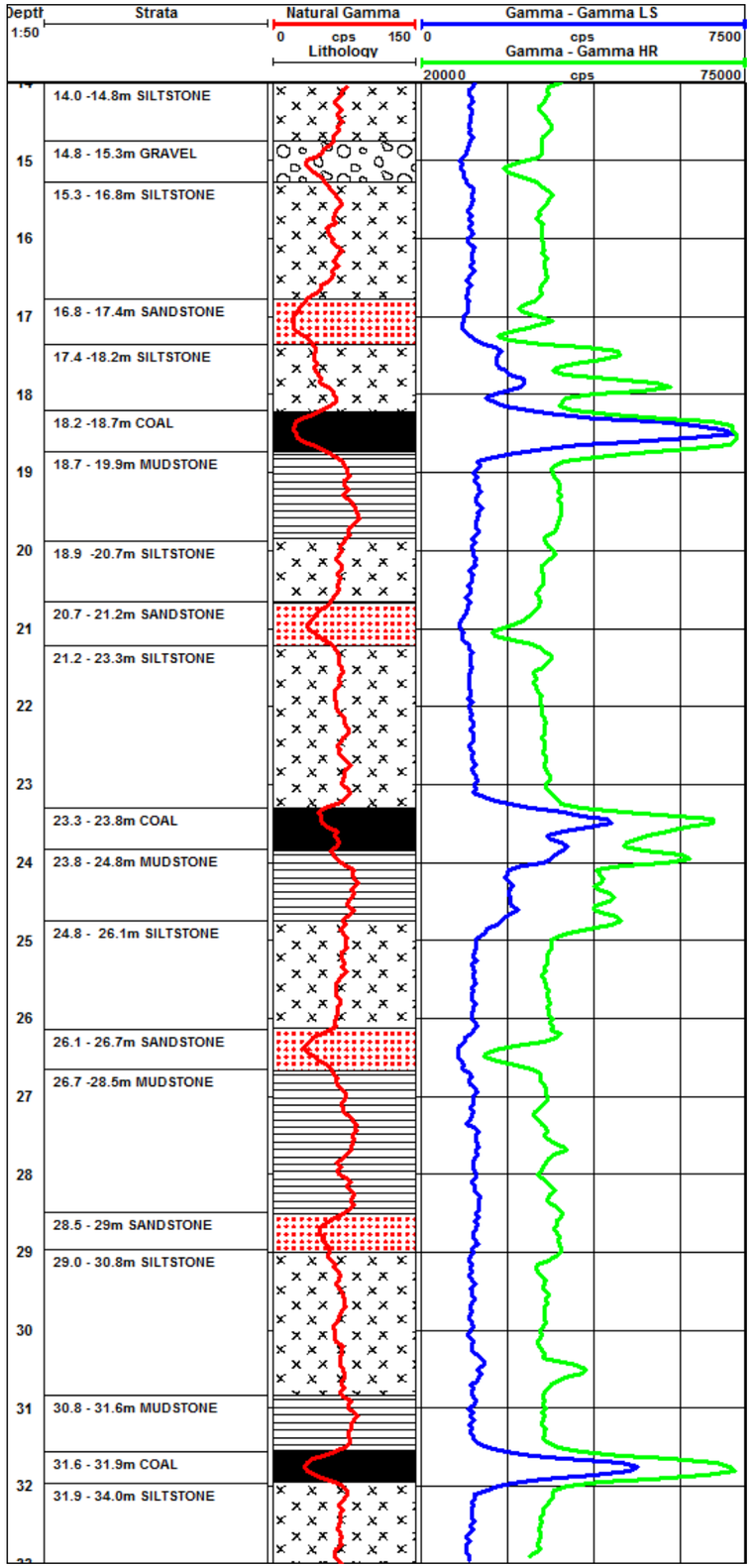


Figure 3. Natural Gamma with Gamma- Gamma logs - Coal Measures.

along with low density (high cps on the gamma-gamma logs).

A typical set of logs with interpretation is given in Figure 3.

"A combination of natural gamma along with caliper... and resistivity is a useful combination in hydro-geological investigations..."

A combination of natural gamma along with caliper (measures borehole diameter) and resistivity is a useful combination in hydro-geological investigations particularly during a drilling program when the logs may be used to evaluate the formation and select a suitable point for setting the permanent casing or screens.

In the example to the right (Figure 4) the natural gamma log was used to pick out the mudstones (high gamma cps) from the sandstone (low gamma cps) bands. The more competent sandstone was then selected by a more regular diameter (caliper) and higher

"The permanent plain casing from ground level was then set within the interval 50 to 60m and grouted."

resistivity values (harder). The permanent plain casing from ground level was then set within the interval 50 to 60m and grouted.

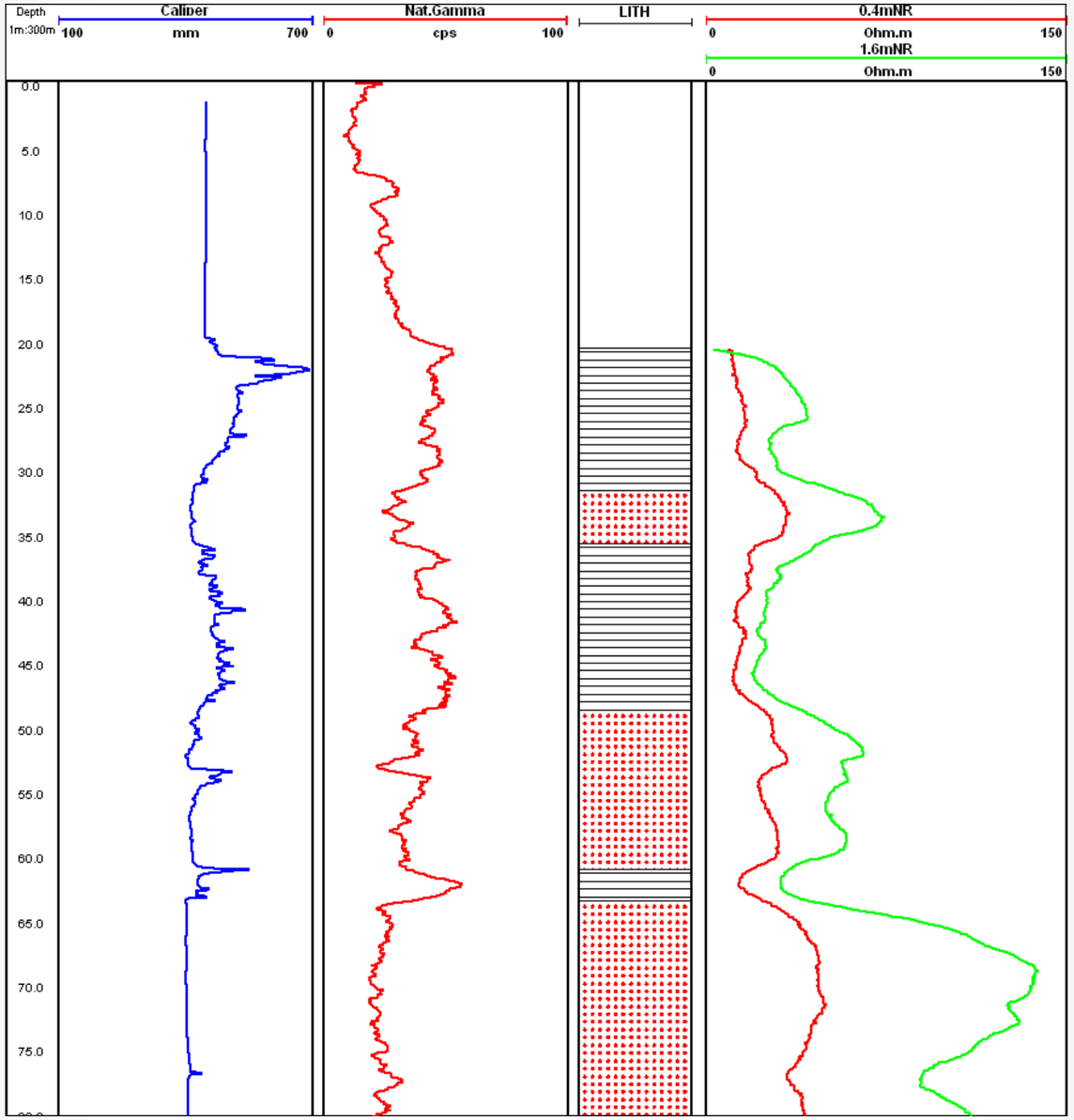


Figure 4. Natural Gamma Logs through Mudstones and Sandstones.

"Chalk has a very low natural gamma response and is readily identified."

Chalk has a very low natural gamma response and is readily identified. By running natural gamma logs at the appropriate time in a drilling project it can enable the casing to be set at the optimum point at or within the top few metres of the chalk. Additionally the formations above the chalk have distinct gamma characteristics as illustrated in the example on the next page – Figure 5. This information can assist in fine tuning the geologist's log and aid in the optimum design of monitoring wells this has proved particularly useful in the London area.

Under favourable borehole conditions natural gamma logs from several boreholes may be used to correlate features across a wide area...

"Under favourable borehole conditions natural gamma logs from several boreholes may be used to correlate features across a wide area..."

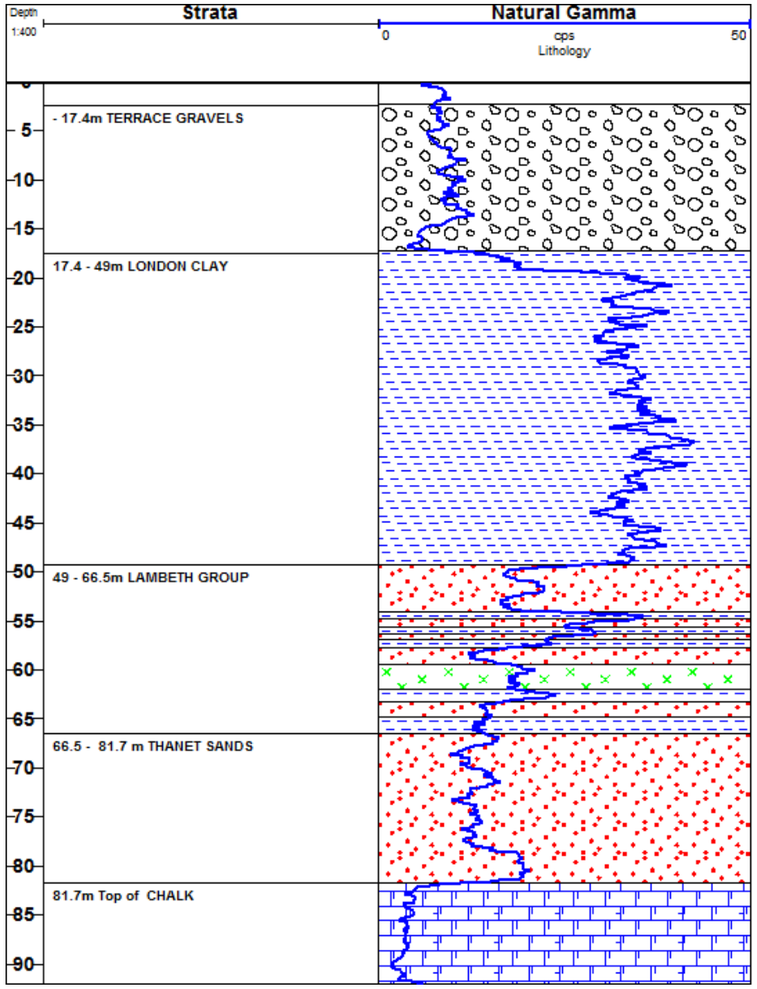


Figure 5. Natural Gamma log and interpretation - London

across a wide area and even allow possible prediction of expected bed horizons. The example to the right (Figure 6) is from a series of boreholes across part of London and illustrates clearly the top of the chalk at each location.

"The right borehole conditions are essential for getting the best out of any geophysical log..."

The right borehole conditions are essential for getting the best out of any geophysical log and logging at the appropriate time in any drilling program is paramount e.g. prior to grouting

"The gamma log may be run under most down-hole conditions i.e through casing, water or air."

or installation of linings. The gamma log may be run under most down-hole conditions i.e through casing, water or air. However these have to be taken into consideration as they each have differing attenuation

"However these have to be taken into consideration as they each have differing attenuation effects on the gamma response so knowing where there are changes is important to making the correct interpretations."

effects on the gamma response so knowing where there are changes is important to making the correct interpretations.

If these are not known they can be determined by other logging methods. Best results are also obtained in narrower rather than larger diameters as the response is a function

"Ideally the down-hole conditions should be kept as constant and consistent as possible..."

of borehole diameter. Ideally the down-hole conditions should be kept as constant and consistent as possible throughout the course of the logging program.

Despite these limitations the natural gamma log is a useful cost effective method that enhances and supplements geological data in a variety of investigations and drilling projects. ■

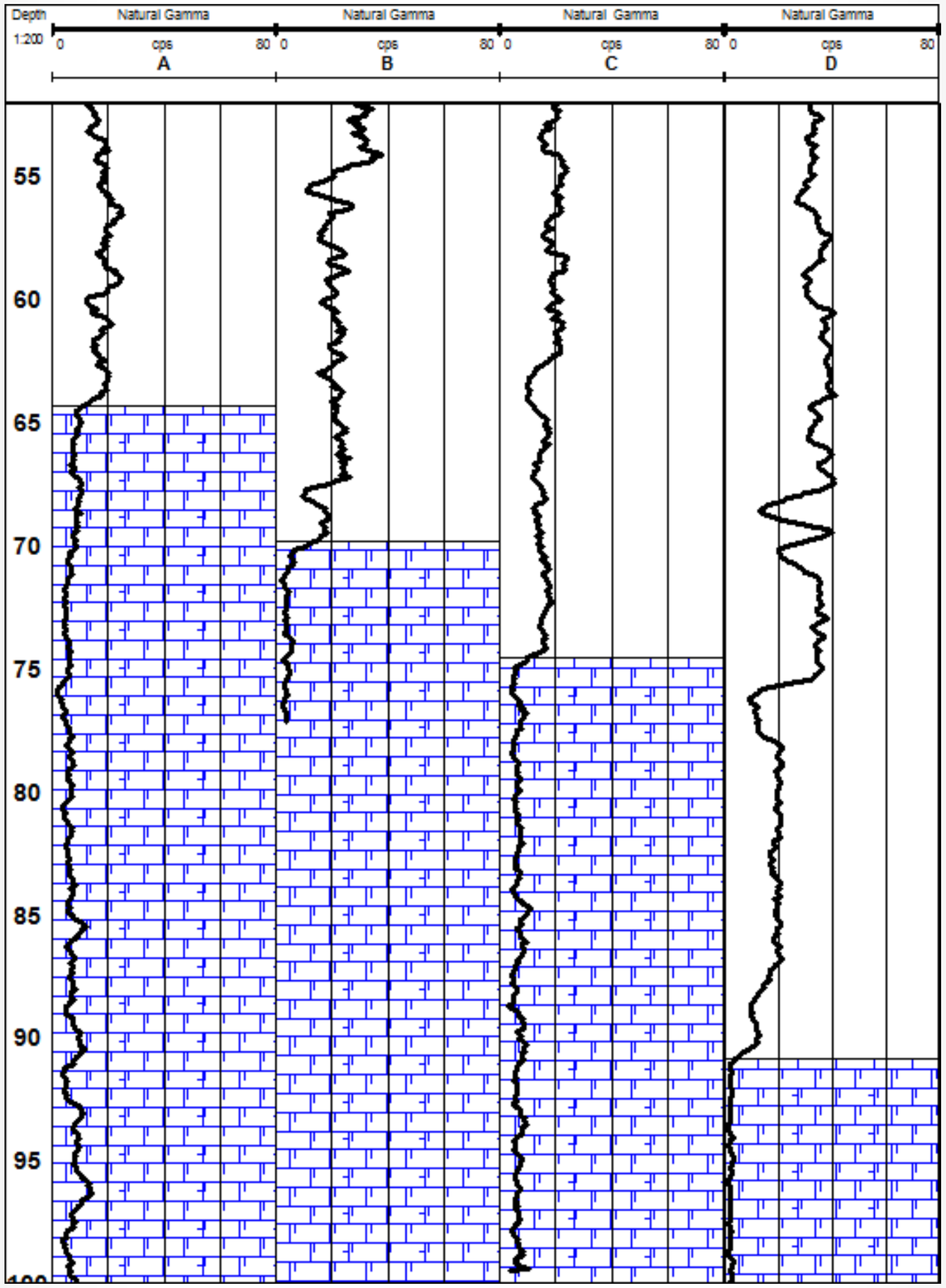


Figure 6. Natural Gamma log correlation between boreholes showing the top of the Chalk

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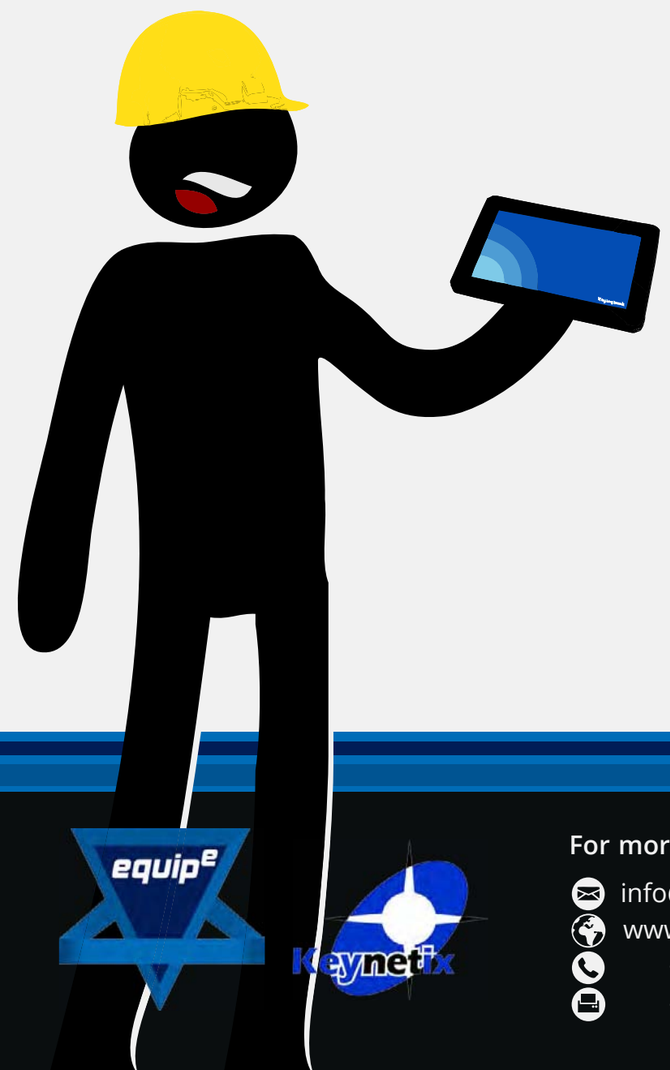

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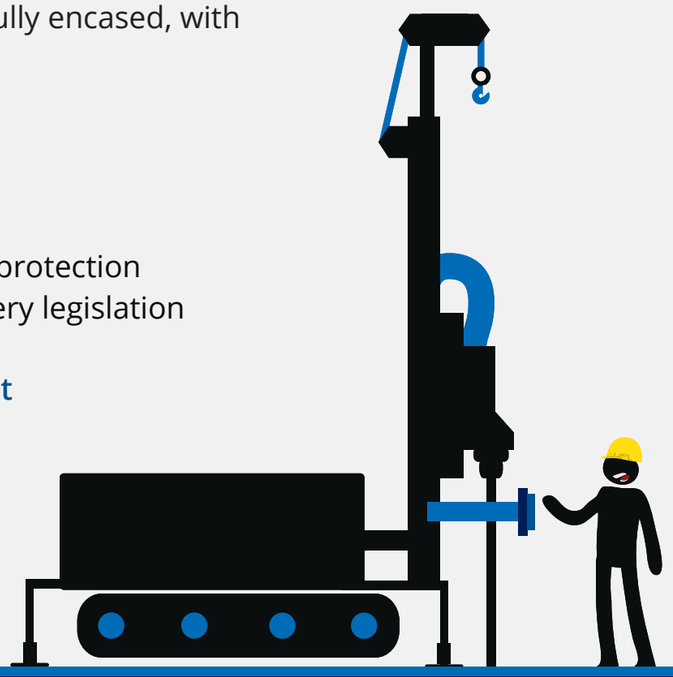

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INVESTIGATING INSTABILITY

*Writing for **theGeotechnica** this month are Martyn Brocklesby and Elizabeth Withington, Director and Senior Manager at Geotechnical Engineering. Last month Pete Reading provided details of the recent survey works carried out on the English South Coast focussing on cliff instability. This month Martyn and Liz provide a perspective on Geotechnical Engineering's ground investigation work carried out on the affected area at Barton on Sea.*

New Forest District Council employed Geotechnical Engineering Limited to undertake ground investigation and monitoring works on the coastal cliffs of Barton-on-Sea, an area affected by coastal erosion.

A ground investigation was required to develop the ground model and contribute to a risk assessment, cliff-stability assessment and design of a site-instability management plan. The engineer to the contract (CH2M Hill) was responsible for designing the investigation to supplement and complement data from numerous previous phases of work. The importance of the work was highlighted in the time between tender submission and prior to the ground investigation starting, when after a period of particularly wet weather, failure surfaces were activated and further significant ground movement occurred.

"The importance of the work was highlighted in the time between tender submission and prior to the ground investigation starting..."

The site comprised the cliff-top plateau and its undercliff seaward of Marine Drive at Barton-on-Sea. The work areas included public and private land, and the access roadways and unstable slopes of the undercliff. Much of the site was within the Highcliffe to Milford Cliffs Site of Special Scientific Interest (SSSI) – a geological conservation site.

"The work areas included public and private land, and the access roadways and unstable slopes of the undercliff."

Geotechnical Engineering Ltd (GEL) was appointed as principal contractor to undertake the ground investigation. The investigation included the construction of 18 boreholes, surface geophysical surveys, down-hole geophysical logging and the installation of multilevel vibrating wire piezometers, inclinometers, open-tube instruments and slip indicator tubes.

The aims of the investigation were clearly defined by New Forest District Council and a series of specific objectives were outlined. These included the detailed logging and classification of samples recovered from the boreholes including the description and identification of the Barton Group and its fossil fauna to allow correlation between boreholes, and identification of any potential failure surfaces.

Site work: Geotechnical Engineering setup at Barton on Sea

Core obtained from the site

"At tender stage GEL made a thorough assessment of the geology, ground conditions and contract documents..."

At tender stage GEL made a thorough assessment of the geology, ground conditions and contract documents and presented both a compliant and alternative approach to the investigation. This reflected GEL's desire to provide the most cost-effective and technically comprehensive solution for this project. The alternative submission was accepted and proved to be technically beneficial to the client and engineer.

The alternative approach was based on using GEL's multipurpose dynamic sampling and rotary-coring Pioneer rig in lieu of traditional cable-tool boring techniques. It subsequently transpired that the client was particularly concerned about the use of traditional percussive techniques near to properties and the unstable cliffs in terms of risk from vibration hazards and noise nuisance. The alternative proposal went some way to alleviate these concerns.

The Pioneer rigs offered unique flexibility insofar as:

Geotechnical Engineering drilling technicians

Installations at the Barton on Sea site

- The lightweight tracked machines minimised unavoidable damage to ground surfaces.

"The combination of dynamic sampling and rotary coring provided a complete strata sequence."

- The combination of dynamic sampling and rotary coring provided a complete strata sequence. Traditional percussive techniques would have been extremely poor given the need to advance the hole by chopping and shelling the clays.

- Issues associated with poor or no recovery and deformation of thin-walled U(T)100 samples in stiff and hard clays were avoided.

"Eurocode (EC7) Class 1 samples were available from cored material."

- Eurocode (EC7) Class 1 samples were available from cored material.

- Correlation of downhole geophysical logs with a complete cored sequence across boreholes added significant technical benefits to the project.

- Budgetary certainty was improved by eliminating the cost of advancing boreholes by chiselling techniques.

- The alternative proposal

"Trained and experienced engineering geologists from GEL carried out detailed logging and interpretation of the stratigraphy on site."

was cost neutral to the client.

Trained and experienced engineering geologists from GEL carried out detailed logging and interpretation of the stratigraphy on site. GEL's approach to logging and exploratory hole-log production ensured that adequate detail was recorded for correlation purposes. This included identification of the Barton Group fossil fauna, adding minor as well as macro strata boundaries, refining log legend detail and adjusting the scale of report outputs to accommodate the additional technical detail.

"The investigation was delivered safely, without incident, in accordance with all safe systems of work, to a high technical standard..."

The investigation was delivered safely, without incident, in accordance with all safe systems of work, to a high technical standard, within budget. The combination of selecting the appropriate ground investigation techniques in the form of the Pioneer rig and detailed logging by GEL engineering geologists ensured the production

"The successful completion of the project reflected a huge team effort..."

of quality site data. The successful completion of the project reflected a huge team effort on behalf of the client and their engineer, together with GEL's management team, project manager, site agent, engineering staff, technicians, drillers, site operatives and sub-contractors. ■

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Specifying Site Investigations
This one day course will look at the various methods available to carry out intrusive and non intrusive investigation. Whilst the course will concentrate on geotechnical methods some geo-environmental methods will be briefly discussed. The course will look at the aims of SI and categorise the various stages in an investigation.

Soil Description Workshop
From 2007 new European Standards have started replacing the British Standards (Codes) under which investigations in the UK have been carried out. UK working practice will have to change to meet these new requirements but few practitioners are aware of the changes or the timetable. The workshop will comprise a series of lectures on the changes, and lectures on soil description followed by practical sessions describing soil samples.

Rock Description Workshop
From 2007 new European Standards have started replacing the British Standards (Codes) under which investigations in the UK have been carried out. UK working practice will have to change to meet these new requirements but few practitioners are aware of the changes or the timetable. The workshop will comprise a series of lectures on the changes, and lectures on rock description followed by practical sessions describing rock and compiling mechanical logs of rock core.

In Situ Testing
The course will cover both the theory and the practice of various In Situ Testing techniques used on typical geotechnical projects. In addition the courses will consider the effect that Eurocodes will have on the UK's current practice. This course provides an overview of in situ tests used in common practice and some of the more specialist tests together with their advantages and limitations.

Instrumentation and Monitoring
The course comprises a comprehensive one day appreciation of the complete process involved in Instrumentation and Monitoring in the geotechnical environment. The course provides an overview of the current guidance documents and their requirements. The course will consider the design of both individual installations and the installation of suites of instruments in the wider site contex.

Basic Foundation Awareness
This one day course will provide a general overview of foundation design. It will include an assessment of the use and choice of shallow foundations and piles. It will cover the derivation of bearing capacity formula and their use. Exercises will be carried out to calculate the working loads and settlement of simple foundations. The methods used to calculate these will be in accordance with those described in Eurocode.

IOSH Working Safely on Geotechnical Sites
This one day course is developed by industry specialists within RPA Safety Services and Equipe Training as a foundation to site safety. Its aim is to impart the core safety skills required of those working on geotechnical sites by building on their existing specialist technical skills. After attending the course, candidates should be able to identify hazards on site, understand basic safety legislation, participate fully and confidently in site safety consultation and manage priority risks to a sufficient standard.

IOSH Avoiding Danger from Underground Services
Partnering with RPA Safety Services once again, Equipe provide another IOSH certified health and safety course. This one day course is aimed at anybody involved in specifying, instructing, managing, supervising or actually breaking ground and really addresses the problems and risks related to underground services, which may be encountered during both planning and execution of geotechnical projects.

IOSH Safe Supervision of Geotechnical Sites
Equipe has partnered with RPA Safety Services, an independent occupational health and safety specialist, to provide a unique IOSH certified course for the Drilling and Geotechnics industry. The three day course is certified by IOSH, is specifically focussed on the geotechnical industry and provides a totally unique and relevant Health and Safety course for managers and supervisors.

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HOW ARE YOU INVESTIGATING YOUR PIPES AND TUNNELS?

*Writing for **theGeotechnica** this month is Geoff Acland, Business Manager of Arrow Geophysics Limited, a geophysical consultancy established in 2004 that provides advice on geophysical risk reduction for UK construction projects. In this, the third of a series of articles, Geoff explains the development of a specific technique for locating and investigating pipelines and tunnels at depth.*

There is a continual drive to improve the efficient use of commercial and residential land and to better manage the complexity of large construction projects. Geophysics engineers are striving for process improvement by the innovative use of the many technologies available and the further development of existing hardware and software.

The two preceding articles in this series have discussed the merits and applications of various geophysics techniques which may be used to identify buried hazards and obstructions found in the top five metres of the subsurface. There are many geophysical options available to the survey designer some which may have performance limitations. The locating of water bearing pipelines at depth is an example. Relative low-tech systems are available to trace the route of services, including pipelines, to depths up to 1.2m. At greater depths and in sympathetic ground conditions Ground Penetration Radar may be more successful. However, there are many water bearing pipelines and tunnels at far greater depths than cannot be explored by conventional geophysics techniques.

“However, there are many water bearing pipelines and tunnels at far greater depths than cannot be explored by conventional geophysics techniques.”

“Most of the pipeline or tunnel asset owners do not possess accurate records of their asset’s location because it was not surveyed immediately post construction.”

Most of the pipeline or tunnel asset owners do not possess accurate records of their asset’s location because it was not surveyed immediately post construction. Many of these constructions are old and what records are available have subsequently been found to be very inaccurate. No problem for the owner of course, his asset is in place, functioning and needing only general periodic maintenance but then along comes a developer or a civil engineering contractor who needs or wishes to build over or adjacent to the actual route of pipeline/tunnel.

To ensure that there is no subsequent “catastrophic construction” which may damage the asset, the owner then suddenly comes alive and the absence of a survey of a verified pipeline alignment imposes an immediate embargo upon proposals to build over or adjacent to the asset. The accurate survey of deep pipelines has proved to be a very difficult challenge for geophysical engineers for many years. In many circumstances land has been sterilised because the recorded presence of a deep tunnel/sewer cannot be verified. The need to address this challenge was becoming ever more apparent.

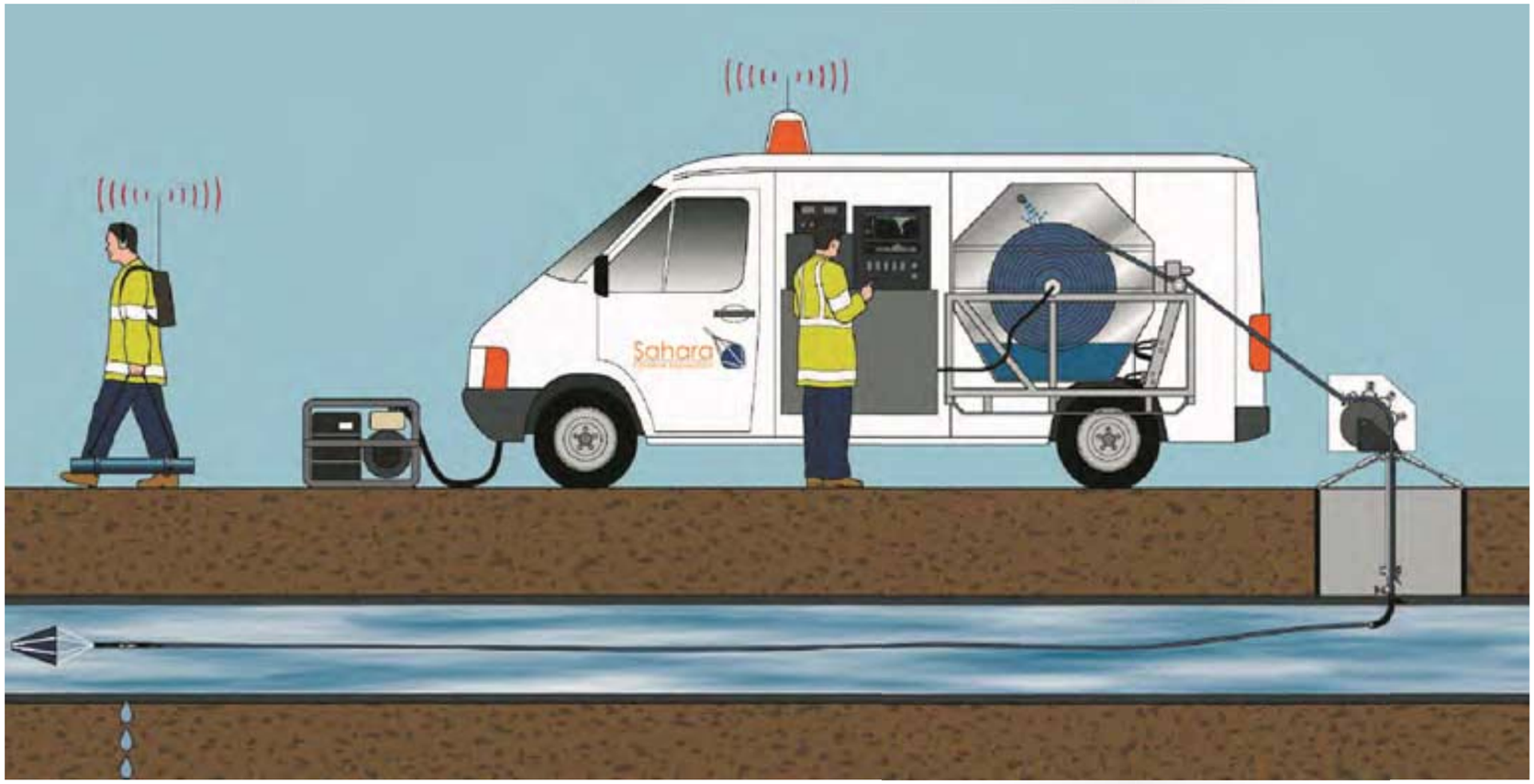
“In many circumstances land has been sterilised because the recorded presence of a deep tunnel/sewer cannot be verified. The need to address this challenge was becoming ever more apparent.”

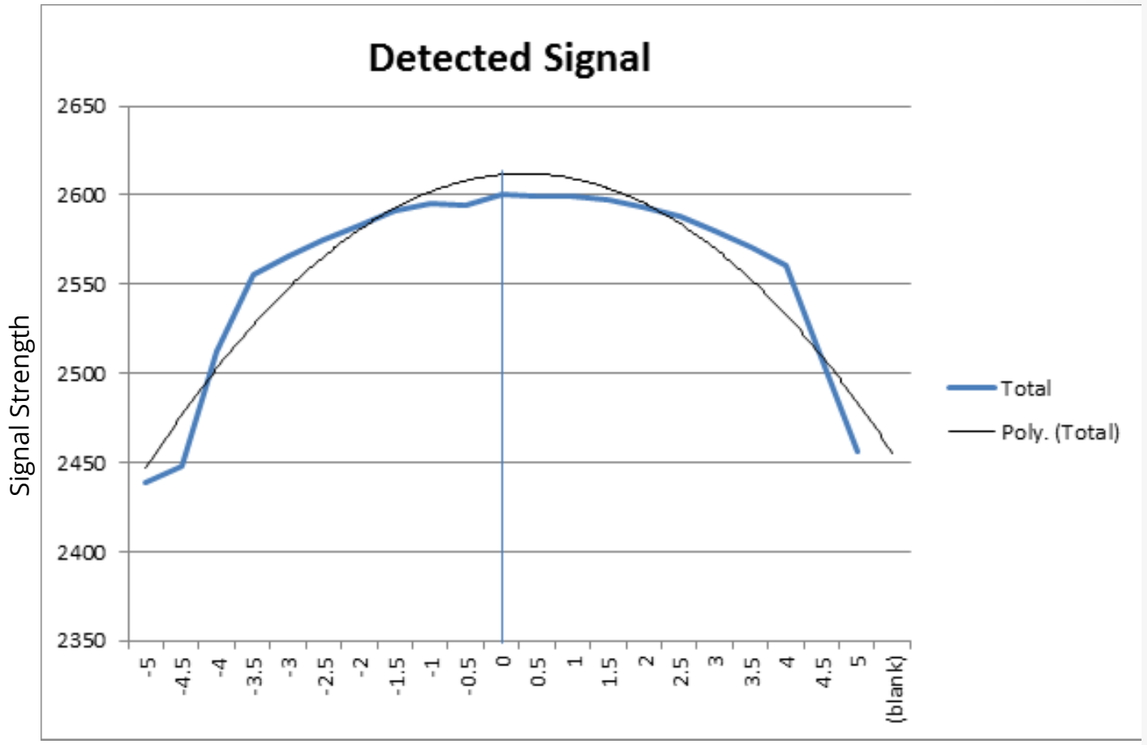
In 2012 a nationwide housing developer needed to secure the expertise to determine of the line of a pressurised raw water main running beneath a major commercial and residential property redevelopment site in South East London. The creation of the scheme layout could not proceed until the main, laid to depths varying between 1.5m and 14m had been accurately located. In the absence of an accurate survey the asset owners sought to impose an exceptionally wide protective easement spanning the theoretical line of the pipeline. This easement had very serious impact upon the scheme both architecturally and commercially. It became absolutely clear that a solution to this pipeline location problem had to be found.

“In the absence of an accurate survey the asset owners sought to impose an exceptionally wide protective easement spanning the theoretical line of the pipeline.”

Modifications to electromagnetic wave technologies were considered but for many reasons, not the least being inconsistent performance in the ever changing stratigraphy and limited depth penetration, they were discounted. The adaptation of an acoustic system previously used to detect leaks in pipelines

“The adaptation of an acoustic system previously used to detect leaks in pipelines was considered...”





through the pipe using a drag parachute in the downstream flows within the pipe to keep the umbilical cable in tension. This allows the system to be used where one (upstream) point of access to the pipe is available.

"The signaller sends signals through the ground to the survey vehicle at the launch point for real time analysis."

The signaller sends signals through the ground (conditions not relevant) to the survey vehicle at the launch point for real time analysis. The location system makes use of communication between the signal generator (within the pipe) and a device carried by an operator walking along the approximate line of the pipe, directly above the signaller in the pipe. When the above ground device is closest to the in-pipe signaller (generally meaning it is directly above) there is a peak in the signal passing between the two devices. Identifying where this peak occurs allows the location of the in-pipe sensor to be determined at the surface.

A schematic of the system is shown above to the left.

Following considerable additional development and testing the system has now been developed to achieve a positional accuracy better than ±0.3m (either side of centreline) at depths of up to 8m and ±0.5m at depths between 8m and 25m. Further analysis of the survey results gives surveyed depths to the pipeline invert.

"After further reassurance testing and software development the asset owner's engineers approved the methodology..."

After further reassurance testing and software development the asset owner's engineers approved the methodology and the survey in south east London was successfully completed in February 2014. The raw water main was accurately located and the alignment of the main was found not to be where shown on their records. The developers preferred scheme design was no longer blighted by the route of the main. In fact the design situation was improved with added commercial benefit.

The system works extremely well. The ability to accurately trace deep pipelines of all types is now available. Further successful projects have been undertaken since the south east London project was completed. The system will next be employed on the survey of a tunnel/storm water relief sewer 2.8m in diameter and 25m deep. This larger structure will be dry when surveyed

"A great deal of research and testing followed and ultimately a system which passes a ultra-high frequency acoustic signaller through the pipeline was chosen."

was considered to be the best way forward. A great deal of research and testing followed and ultimately a system which passes a ultra-high frequency acoustic signaller through the pipeline was chosen. The signaller is tethered to the surface via an umbilical cable and the unique signal itself is detected by a surface tracking device. The signaller is carried

"Further successful projects have been undertaken since the south east London project was completed."

and of course the signaller will need to be manually positioned within the pipeline to ensure that either the invert level (or the soffit level) is located. There is only one point of access to the tunnel available and the tunnel length to be surveyed exceeds 400m.

"There are many ambitions for the future development of the deep pipeline location system..."

There are many ambitions for the future development of the deep pipeline location system including the creation of a remote controlled mainline steerable tractor unit fitted with CCTV, the acoustic location device and a laser scanner which will avoid the need for man entry to larger structures.

"The deep pipeline location system is just one example of innovative thinking driven by the need to resolve a specific problem. Geophysics is an ideal platform for innovation."

Loading signaller and umbilical cord into an upstream air admittance valve on a pressurised main which becomes 14m deep downstream .

The deep pipeline location system is just one example of innovative thinking driven by the need to resolve a specific problem. Geophysics is an ideal platform for innovation. In the opening article in this series Tim Archer wrote "over the past twenty five years there has been an upsurge in the use of non-intrusive geophysical techniques to remove the need for guess work when it comes to locating hazards and obstructions within the shallow sub-surface!" However in the UK the upsurge is still to happen for the location of plant, tunnels etc. at depth. Investigation by excavation is costly and rarely practical. In the absence of a proven methodology technical specialists including asset owners have had no choice but to be ultra-cautious when planning a scheme around the recorded position of the asset. Now, certainly with respect to water bearing tunnels and pipelines (which let's face it constitute the majority of deep structures), they can be located to a far greater degree of accuracy than ever before. ■

"Investigation by excavation is costly and rarely practical."

ADAPTIVE OEDOMETER AUTOMATION

In this month's issue of theGeotechnica we have Diogo Teles of GDS Instruments writing the first in a series of articles for us. This month's offering sees Diogo discuss the automation of oedometer testing and determination of the end of primary consolidation.

Recent years have brought us a wide range of testing apparatuses which allow computer control of test procedures, providing users with decreased operational complexity and increased reliability. Many of the current one-dimensional consolidation systems already do away with the need for bulky weights, replacing them with pneumatic, hydraulic or electro-mechanical systems for the application of vertical load during a test.

"One of the main advantages of oedometer automation is the possibility to run a series of tests more quickly than when manually driven..."

One of the main advantages of oedometer automation is the possibility to run a series of tests more quickly than when manually driven by allowing the software to make decisions about end of loading increment timings. However, full automation of incremental loading and unloading for a complete oedometer test is still difficult to achieve in a reliable and sophisticated way, with automation being typically achieved through a combination of user-defined time limits and analysis of raw (or calculated) data. Testing specimens from different soil types and geotechnical contexts implies variability in consolidation behaviour, which in turn means the same automation trigger may not be applicable for different specimens. This also unfortunately means most current automation methods offer no saving in the total oedometer test length. To address these issues GDS Instruments developed a data analysis methodology, independent of the magnitude of test parameters, which allows oedometer automation algorithms to adapt to specimen behaviour. The result of this was the creation of an Adaptive Oedometer Automation feature, which allows users to conduct oedometer tests significantly faster without compromising the quality of test data.

"This also unfortunately means most current automation methods offer no saving in the total oedometer test length."

1 SELECTION OF AUTOMATION TRIGGER STATES

Standardised oedometer test methodology requires the incremental application of a vertical load on a laterally confined specimen. To be able to determine consolidation parameters for each load increment, time-deformation readings are recorded, plotted to a square root or logarithmic scale, and analysed using a curve fitting method. Reliable automation of the transition between loading increments requires the identification of a trigger state indicative of the end point of a load increment, corresponding to the time when enough data has been recorded to comply

"Reliable automation of the transition between loading increments requires the identification of a trigger state..."

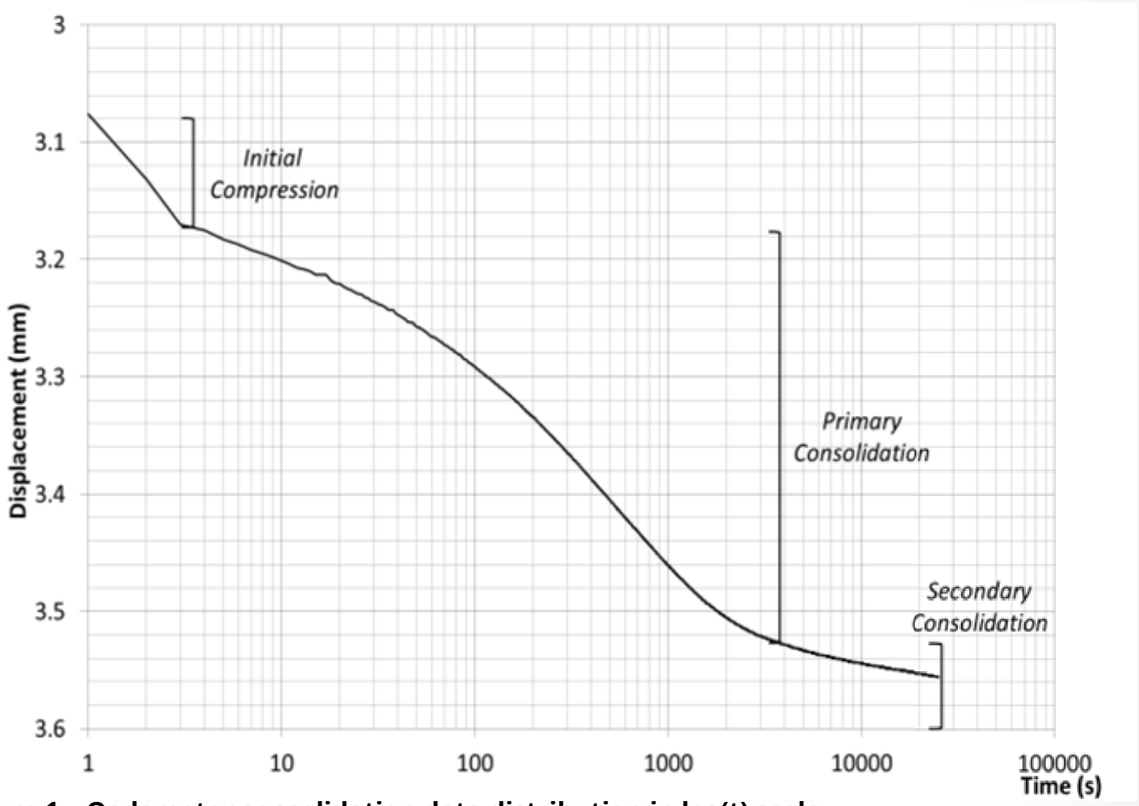
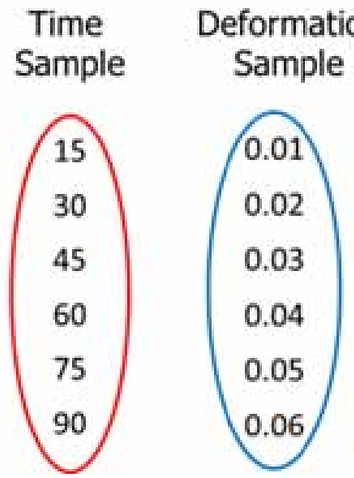


Figure 1 – Oedometer consolidation data distribution in log(t) scale.

Time	Deformation
15	0.01
30	0.02
45	0.03
60	0.04
75	0.05
90	0.06



"To ensure repeatability and applicability of the automation method, this conditional trigger must not be affected by the variability between soil types."

with test standards. To ensure repeatability and applicability of the automation method, this conditional trigger must not be affected by the variability between soil types.

During consolidation of a soil specimen under a given loading increment, deformation varies in magnitude depending on the characteristics of the soil being tested, but will maintain a characteristic time-deformation data distribution. Discrete specimen behaviour during consolidation (namely initial compression, primary and secondary consolidation) can be identified within this distribution. Standard test methods rely on this relation for the determination of consolidation parameters using curve fitting methods, and state that when a specimen finishes primary consolidation for a given load increment enough registered data will be available for the application of at least one of the curve fitting methods available (BS1377: Part 5: 1990; ASTM D2435/D2435M-11 etc.) Thus GDS Instruments considered the onset of secondary consolidation, which by definition happens after the completion of primary consolidation, would constitute a reliable condition to trigger the transition to the next load increment.

"Thus GDS Instruments considered the onset of secondary consolidation, which by definition happens after the completion of primary consolidation..."

2 GRAPHICAL DEFINITION OF SECONDARY CONSOLIDATION

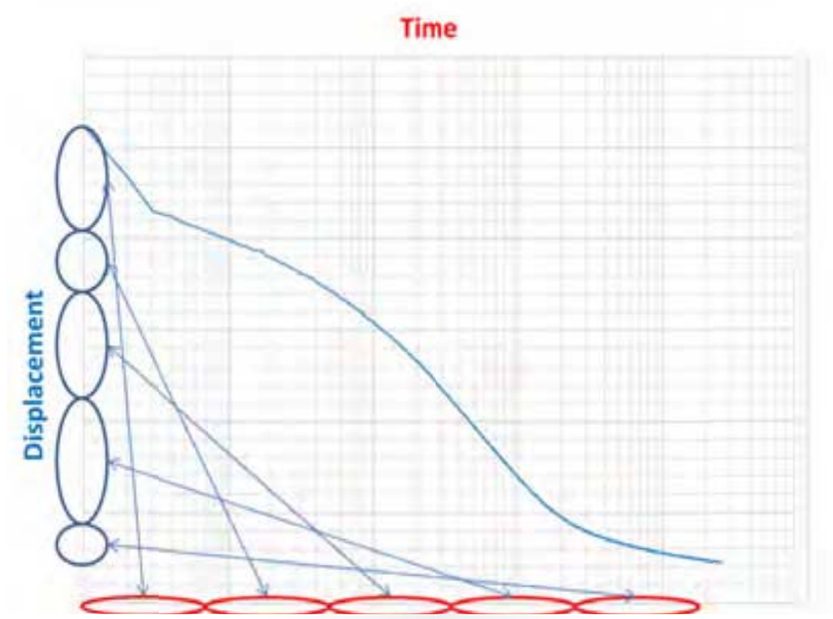


Figure 2 – Data sampling.

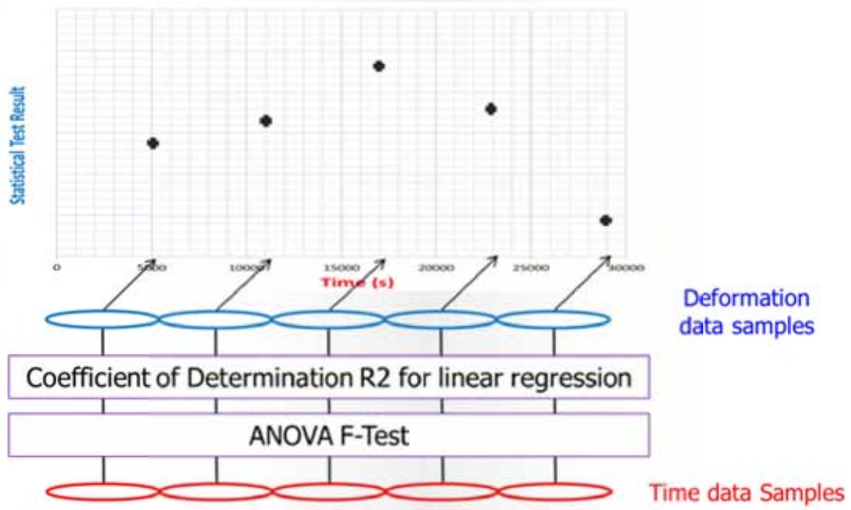


Figure 3 – Back-plotting of statistical indicators.

To graphically represent secondary consolidation during trial tests performed on remoulded clay, deformation data was plotted against time in seconds on a logarithmic scale, according to the curve fitting method suggested by Casagrande. This method was chosen because it typically requires a longer increment duration than Taylor's root of time curve, providing a larger data set for the same data acquisition frequency.

3 ADAPTATION OF THEORETICAL ONE-DIMENSIONAL CONSOLIDATION BEHAVIOUR FOR SOFTWARE DEVELOPMENT

Curve fitting methods are practical and easy to use; however, the design of an algorithm capable of performing the conceptual shape analysis... can be very challenging and resource consuming."

shape analysis needed for these methods, which comes naturally during direct human interaction, can be very challenging and resource consuming. To circumvent this issue GDS Instruments used a statistical approach to virtually quantify the shape of the theoretical consolidation data distribution, creating a nominal numerical parameter directly independent of any other test variable apart from its data distribution, easily implementable within an

"This was achieved by splitting test data from the loading increment into consecutive, isochronal data intervals."

algorithm. This was achieved by splitting test data from the loading increment into consecutive, isochronal data intervals. Each is then split into two different non-overlapping and statistically comparable samples, one composed by time values and the other by deformation values.

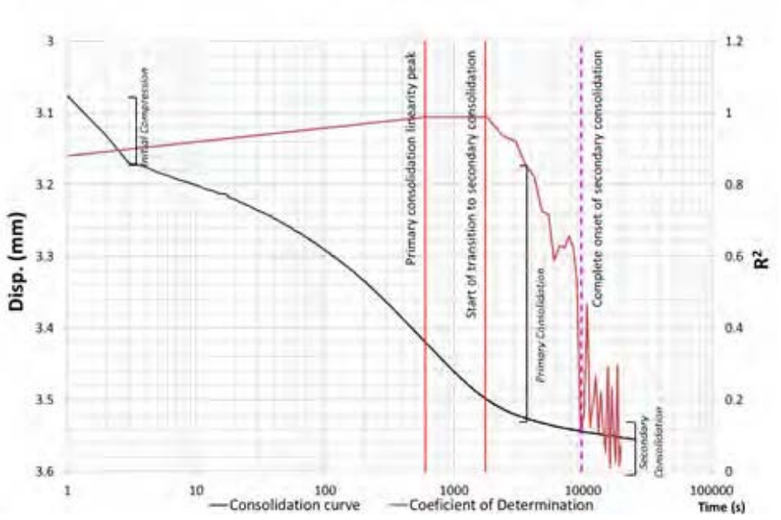
Each deformation sample was compared to its corresponding time sample using statistical methods based on Analysis of Variance (ANOVA) statistical models, providing a numerical indicator of consolidation behaviour for the time interval defined by the time sample. The result of the analysis of consecutive sample pairs can then be plotted against time as illustrated in Figure 3, using the largest time value for each sample on a logarithmic scale, and compared directly with the shape of the corresponding theoretical consolidation curve.

"To obtain a nominal numerical value for each pair of samples using the ANOVA statistical models, the applicability of a linear regression model was tested by calculating the coefficient of determination (R2) for each pair of samples. "

To obtain a nominal numerical value for each pair of samples using the ANOVA statistical models, the applicability of a linear regression model was tested by calculating the coefficient of determination (R2) for each pair of samples.

"The F-Test was also used to quantify the relation between time and deformation statistical variability."

The F-Test was also used to quantify the relation between time and deformation statistical variability. Having control of time data (by selecting a constant time interval between observations)



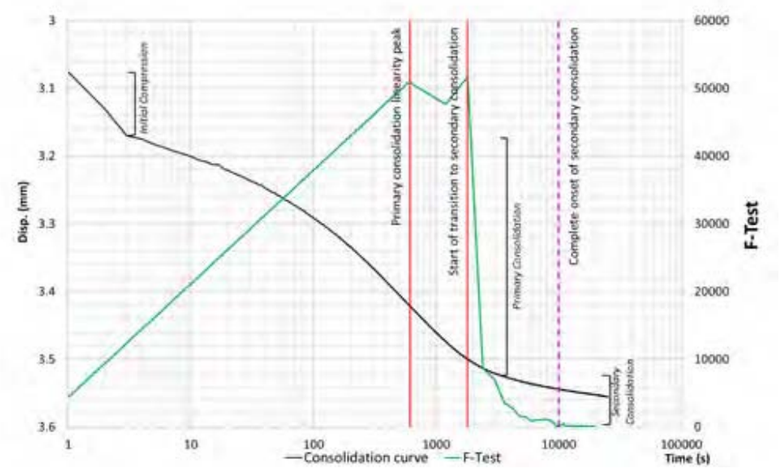


Figure 4 – Relation between consolidation curve, R2 and ANOVA F-test sample analysis.

means the result of ANOVA's F-Test will constitute a good numerical indicator of the variability of deformation data in relation to time.

Figure 4 compares the results of both models with data from a consolidation loading increment on a clay specimen, in which the vertical stress was increased from 400 kPa to 800 kPa. This graphical comparison shows a discernible relationship between the behaviour of the statistical indicators and time-deformation data distribution. The same analysis was repeated, with identical results, for different loading increments on different

"There is an increase of the test parameter value as the consolidation curve approaches linearity..."

soil specimens. There is an increase of the test parameter value as the consolidation curve approaches linearity during primary consolidation, progressing to an accentuated drop in the statistical test results during the transition between primary and secondary consolidation, and a final stabilisation at a lower value when secondary consolidation

"Although this behaviour is observed for both indicators, the coefficient of determination shows a milder reaction to changes in the consolidation curve..."

is ongoing. Although this behaviour is observed for both indicators, the coefficient of determination shows a milder reaction to changes in the consolidation curve when compared to ANOVA's F-test, in addition to increased variability during secondary consolidation.

This association between the onset of secondary consolidation and stabilization of F-Test at a lower value relative to a previously identified maximum constitutes an objective indicator useful for

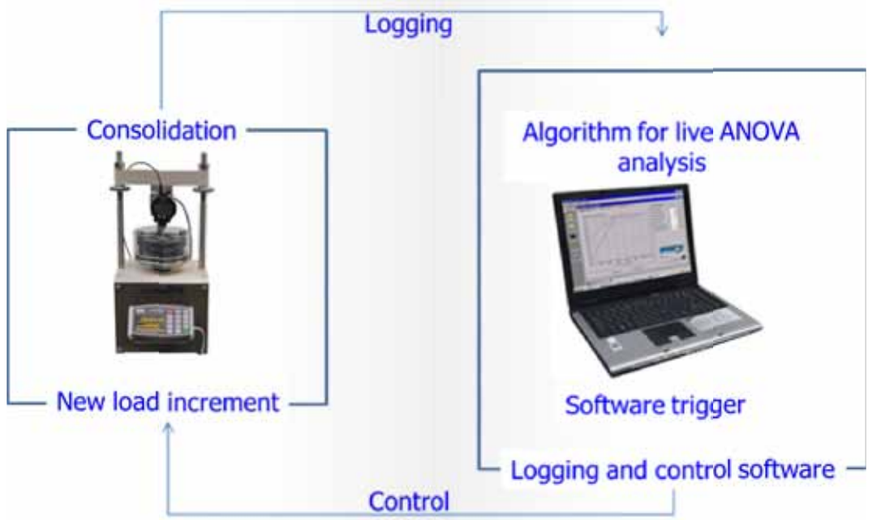


Figure 5 – Adaptive Oedometer Automation.

viable software implementation during the automation of transition between load increments.

4 IMPLEMENTATION

The F-Test statistical indicator was chosen over the coefficient of determination to identify the point at which primary consolidation is complete. Using it, a condition was implemented within GDSLAB software to trigger the transition during oedometer test control.

"To accomplish this, test data was analysed to determine the value of F during secondary consolidation."

To accomplish this, test data was analysed to determine the value of F during secondary consolidation. Since the data distribution is independent of the magnitude of displacement or the units in which values of time or displacement are expressed, values of F are identical between different specimens. This allowed GDS Instruments to specify a simple condition stating that when F goes under a specific value primary consolidation has ended and the control software can execute the transition to the

"This condition has to befulfilledforanumber of consecutive pairs of data samples before the software triggers the transition..."

next increment. This condition has to be fulfilled for a number of consecutive pairs of data samples before the software triggers the transition, which increases reliability by avoiding issues related to data noise or abnormal readings.

This method was used to create an Adaptive Oedometer Automation feature not only capable of running an oedometer test without any user intervention between the beginning and end of a test, but also capable of organizing test processes in such a way that no time will be spent acquiring data that will, in the end, be irrelevant for test reporting. This is done through constant monitoring and analysis of live test data and automatic application of control parameters when trigger conditions are met, as illustrated in Figure 5.

5 TRIAL TEST RESULTS

Tests conducted on clays using GDSLab software to control a GDS electro-mechanical Automatic Oedometer System (GDS AOS) showed a consistent automated transition between load increments occurring at the start of secondary consolidation. Manual data analysis using the log time method confirmed there was enough data recorded from each stage to accurately determine standard consolidation parameters.

Further data obtained from tests using the same apparatus showed a decrease in total test time without loss of

"Testing is still being conducted to quantify this decrease in test duration, although it will be difficult to generalise the results..."

relevant data. Testing is still being conducted to quantify this decrease in test duration, although it will be difficult to generalise the results due to variations between specimen characteristics. However, at this early stage of testing results obtained from tests conducted on over-consolidated clays, using GDS' Adaptable Oedometer Automation feature and electro-mechanical load frame, showed an average test duration decrease of 42 % in relation to the 24 hour increments suggested by BS 1377: Part 5: 1990. Given its nature, the ANOVA F-test trigger will activate at the onset of secondary consolidation, even for specimens requiring longer consolidation times (i.e., above 24 hours), unless a user defined duration limit is established. ■

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