ADAPTIVE OEDOMETER AUTOMATION

In this month's issue of theGeotechnica 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.

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.

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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 also allows users to conduct oedometer tests significantly faster without compromising the quality of test data.

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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

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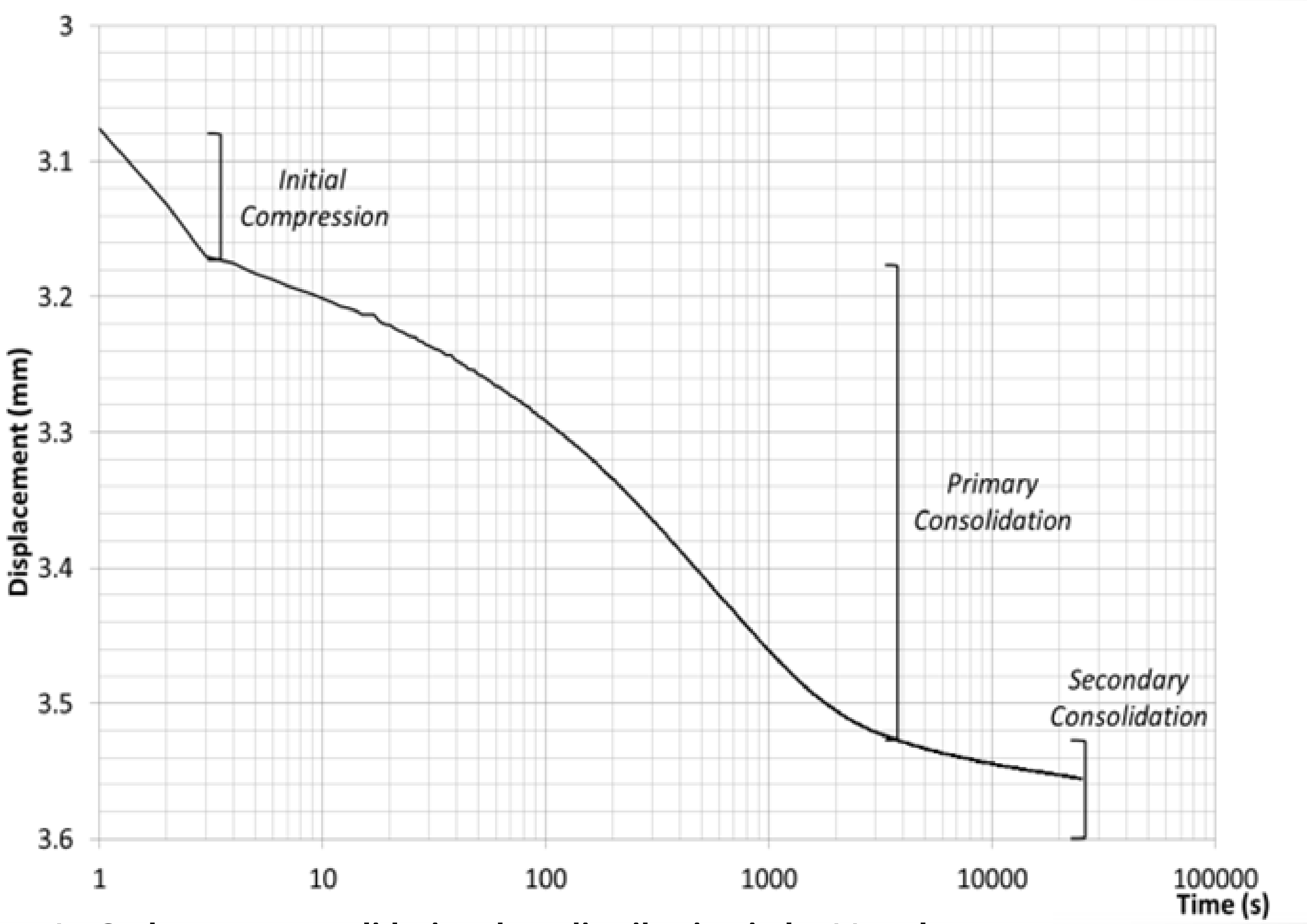
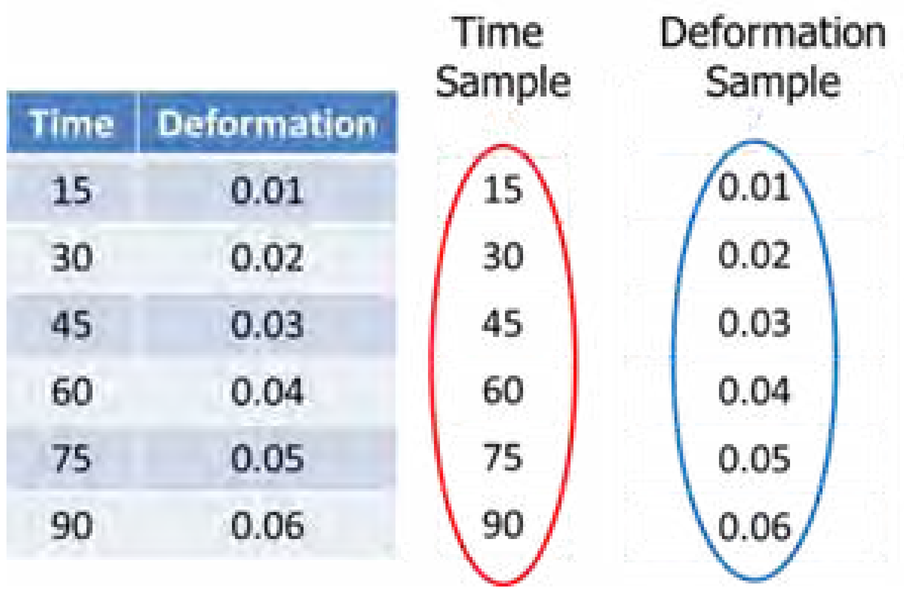


Figure 1 – Oedometer consolidation data distribution in log(t) scale.



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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

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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.

2 GRAPHICAL DEFINITION OF SECONDARY CONSOLIDATION

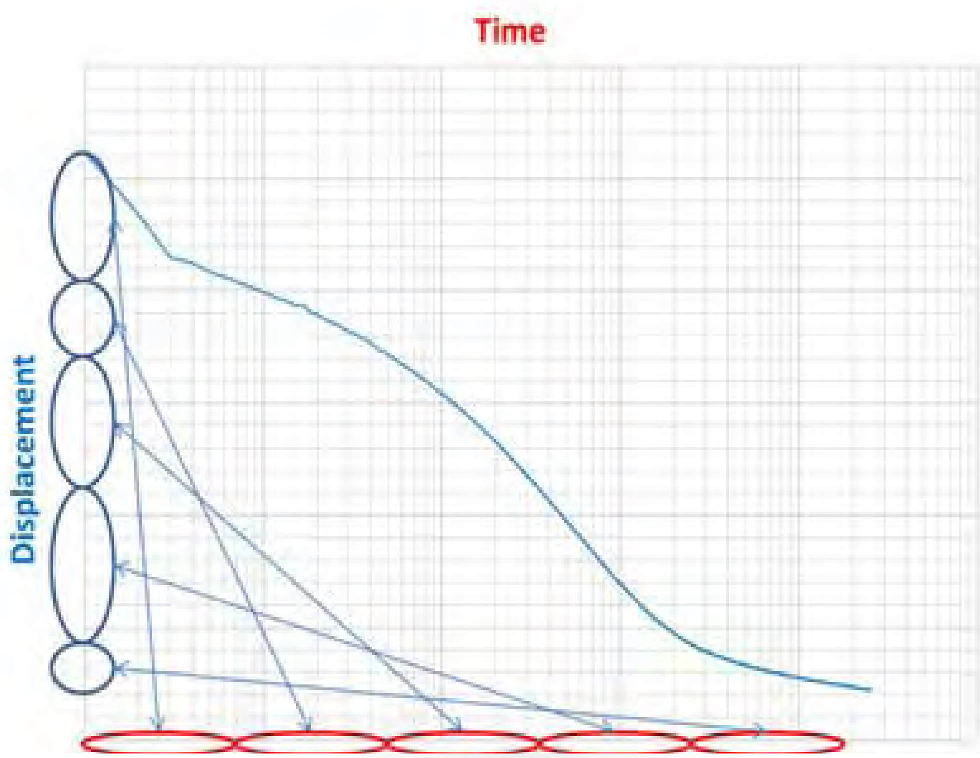

Figure 2 – Data sampling.

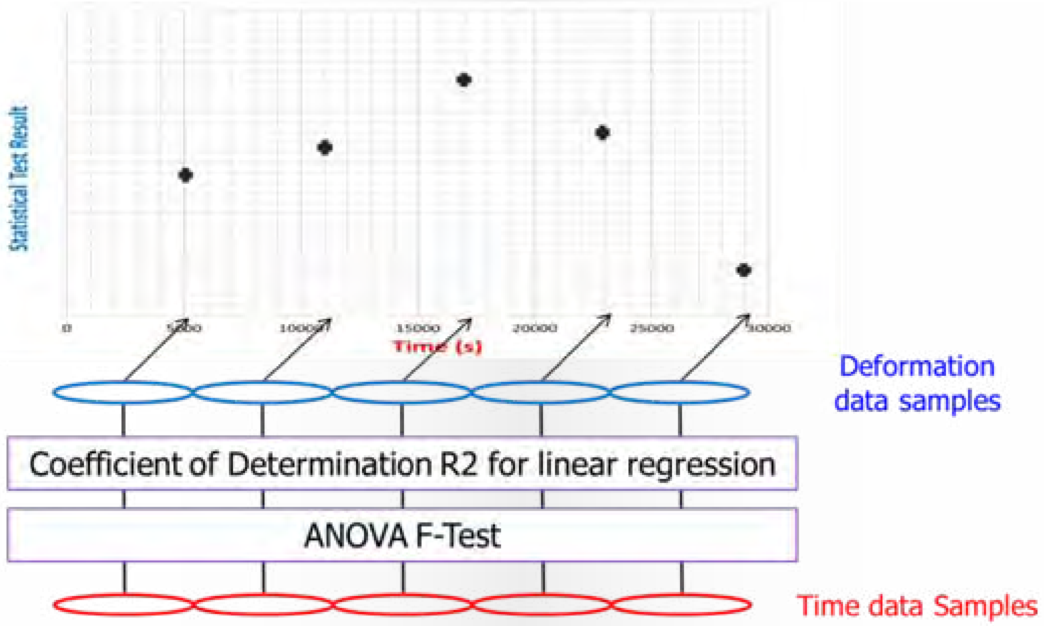

Figure 3 – Back-plotting of statistical indicators.

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

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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

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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.

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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 (R^2) for each pair of samples.

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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) ▶▶

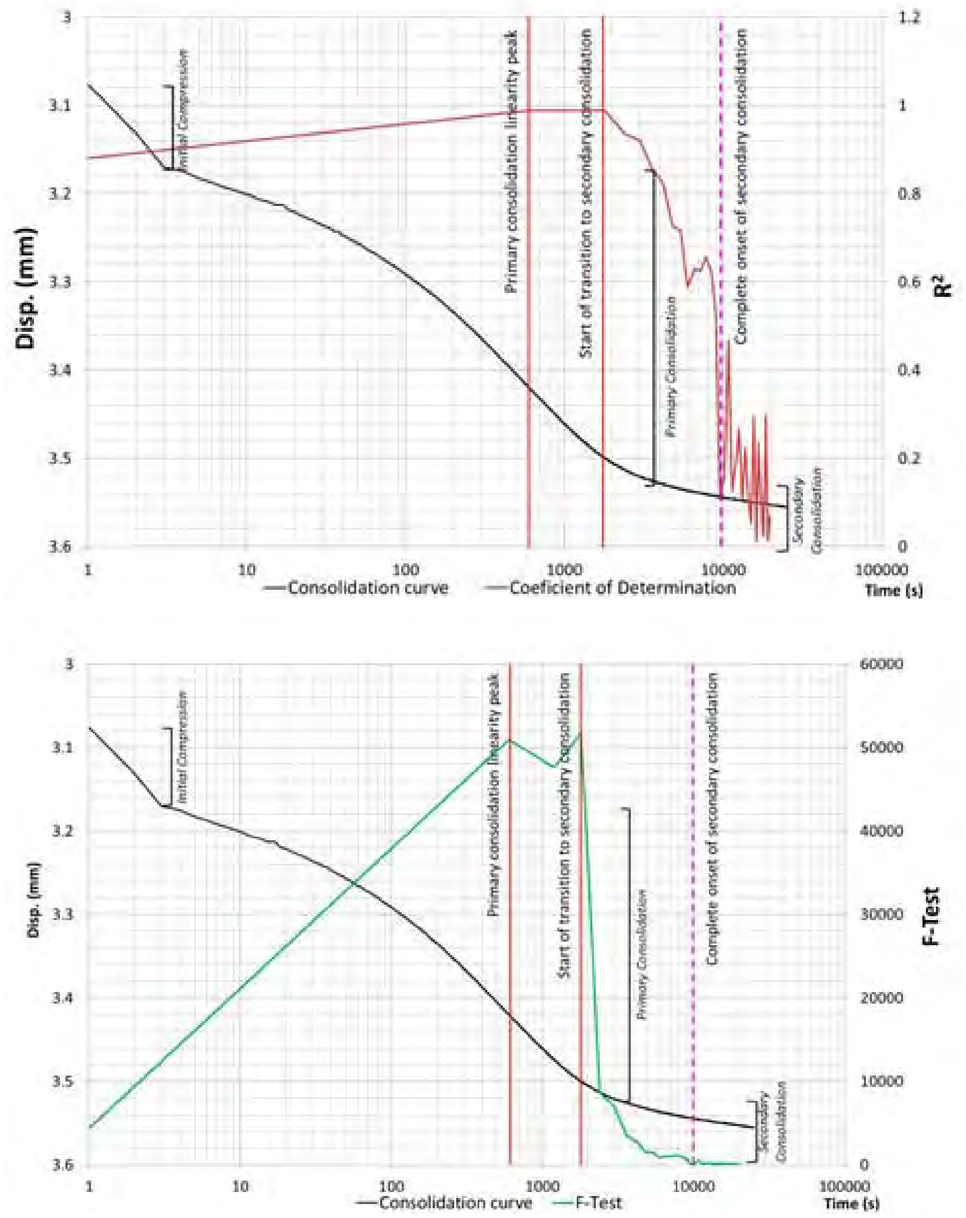

Figure 4 – Relation between consolidation curve, R2 and ANOVA F-test sample analysis.

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

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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

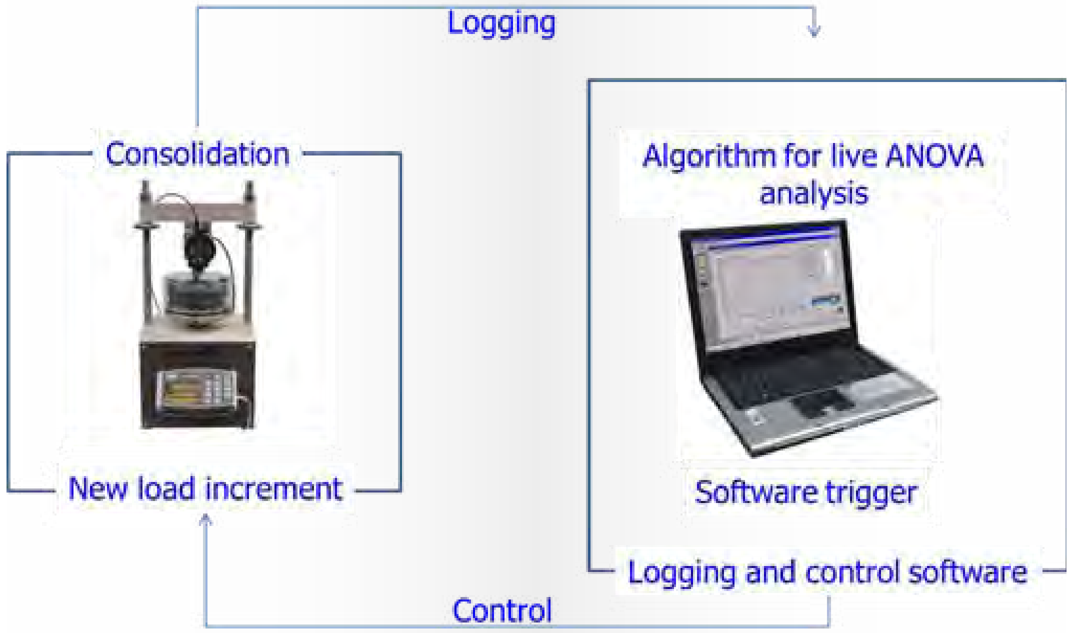

Figure 5 – Adaptive Oedometer Automation.

during the transition between primary and secondary consolidation, and a final stabilisation at a lower value when secondary consolidation

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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 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.

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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

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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

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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. ■