APPLYING DIGITALIZATION TECHNIQUES FOR GROUTED ANCHOR TESTING

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ABSTRACT

Grouted anchors are unique geotechnical installations in that each must be subjected to testing before judged suitable for service. The testing usually involves subjecting the anchor to tensile loading, monitoring either tendon displacement or load loss, and assessing the results against established acceptance criteria. This process can be time-consuming often involving engineers recording information in the field on paper and digitizing the data later to carry out calculations. Laptops are used on some projects but are not well suited to the rigours of a construction site environment. With complete analysis and data management capabilities, a portable tool has been developed to create greater efficiency in the anchor testing process. The innovative software solution has two components: AnchorTest App, a tablet app that runs on the Apple iPad platform; and AnchorTest Cloud, a back-end website and database running on Amazon Web Services accessible online from any device (e.g., PC, mobile phone or tablet). The app is programmed to accommodate the major international anchor testing codes, including PTI DC35.1-14 (2014) and the European testing standard EN ISO 22477-5:2018 (Test Method 1). It also incorporates a uniquely intuitive user interface. This paper describes how the app utilizes digitized anchor load and extension data for real-time analysis with particular reference to the creep rate analysis in EN ISO 22477-5:2018, and presents examples of the use of the tool on international projects.

Keywords: anchor, grout, digital, real-time, monitoring, testing, acceptance criteria, loading, displacement, tablet app, cloud computing

INTRODUCTION

Cement-based grout is typically the medium that permits the transfer of tensile forces from the anchor tendon to the surrounding ground. However, it is generally acknowledged within the anchor industry that since ground is highly variable, and anchor performance is sensitive to construction processes, the integrity of in situ placed grout cannot be guaranteed. Whether the grout is placed under gravity via a tremie pipe or with external pressure injection, there is no guarantee that the bond at the ground/grout and grout/tendon interfaces will be satisfactory for effective load transfer. Consequently, load testing is mandatory for all grouted anchors before they are judged suitable for service. Across Europe and worldwide, different approaches to anchor testing have evolved, albeit they are generally based on applying a tensile load to the anchor installation and monitoring its behaviour against established acceptance criteria. Such criteria provide limits for load transfer and the anchor's ability to sustain its load within acceptable limits of creep or load loss. Essentially, acceptance tests (referred to as proof tests in the USA) are carried out on all anchors and demonstrate the short-term ability of the anchor to support a load that is greater than the design load and to assess the efficiency of load transmission from the anchor head to the bonded zone within the ground.

On many construction sites, the recording of anchor load and corresponding tendon deformation is routinely carried out manually on notepads or recording sheets. Assessment of the data is difficult when just viewing a series of numbers in a table, therefore graphical representations of load versus deformation are a convenient way to quickly establish whether the anchor's response to loading is elastic, or to identify the point of incipient plastic deformation or failure. In the early applications, back in the 1960s and 1970s, graphs were often plotted by hand. This laborious exercise was made more efficient with the use of software on desktop computers in the office and subsequently developed to the use of laptop computers on site.

However, experience has shown that the typical anchor construction site is not an environment conducive to the safe use of laptop computers. Dirt and dust in the keyboard and susceptibility to damage are amongst the hazards that limit the efficacy of laptop usage on active construction sites. Given the essential requirements for robustness, portability and speed of operation, it was judged appropriate to develop a data management and analysis tool for use on a tablet. Tablets have seen increased popularity across many industries, including geotechnical and civil engineering, by providing engineers with a facility to analyse and manage data in real-time which can improve efficiency, and safety thereby reducing mistakes.

AnchorTest is a unique tool that is specifically designed to provide engineers, engaged with anchor testing, a means to process and manage digitized load versus deformation data. Subsequent analysis can be carried out with greater speed and accuracy giving access to instantaneous feedback on the performance of anchors in relation to established acceptance criteria. This paper describes the software and its modes of operation with particular reference to the implementation of the relatively new European testing standard EN ISO 22477-5:2018. The functionality of the app will also be illustrated by using examples of actual applications undertaken in various parts of the world using other codes of practice.

ESSENTIAL FEATURES OF ANCHORTEST

AnchorTest has two main components: a tablet app that runs on the Apple iPad platform; and a cloud back-end website and database running on Amazon Web Services accessible online from any device (e.g., PC, mobile phone or tablet). Currently, the app is programmed to accommodate full data analysis in accordance with EN ISO 22477-5:2018 (the International Standards Organisation standard for the testing of grouted anchors, Test Method 1), PTI DC35.1-14 (Recommendations for Prestressed Rock and Soil Anchors, 2014) and BS8081:1989 (the former British Standards Code of Practice for Ground Anchorages). BS8081:1989 has been included since some parts of the world still implement this code for anchor testing. Further updates will provide the user with access to EN ISO 22477-5:2018, Test Method 3. Although the software caters for the major international anchor testing codes, users can also arrange unique access to bespoke modules within the software that specifically caters for the requirements of particular specifications. This means that it is currently the only device that permits anchor testing analysis across different codes and standards within one device.

One of the main design features is the intuitive user interface, i.e., no instruction manual is required permitting an engineer, familiar with the testing of anchors, to navigate through the various screens. The software also provides Cloud synchronisation facilities that permit any authorised user (e.g., contractor's engineers, anchor expert or client's engineers) to access the data and analyse the output from a remote location via the internet using a username and password. This facility can be conveniently integrated into the project's QA/QC system.

The relevant physical properties of the anchor are input by the user in the *ANCHOR SETUP* screen and the tables required for the presentation of field data are automatically generated for the nominated number of loading cycles on the *STRESSING OPTIONS* screen. As the field data are generated, they are conveniently typed into the iPad via real-time on-screen guidance. In addition, data plotting with a built-in timer, photographic image and user-notes capture capabilities are available via the *TESTING* screen. The analysis of creep is carried out instantaneously and the user is informed of anchor performance via dialogue boxes that pop up throughout the testing process, providing real-time feedback on the creep behaviour and the apparent tendon free length assessment of the anchor.

On completion of data collection, the user is able to synchronise the data to the Cloud database and the AnchorTest software produces a Microsoft Excel compatible spreadsheet comprising; an overall results summary table (indicating conformant and non-conformant anchors), test readings, analysis results, test plots (cyclic loading data), apparent tendon free length plot and any notes that have been recorded during testing. The user is also able to access location, weather and photographic information which is stored in the Cloud database for the particular test.

Additional features include a battery power assessment, where the software calculates the length of the test and compares it to the battery life available. If the power level is inadequate then the user is reminded to connect the iPad to an external power source (e.g., portable battery or mains) before commencing with the test.

EN ISO 22477-5:2018 IMPLEMENTATION

The testing standard EN ISO 22477-5:2018 describes three test types. The investigation test is a load test to establish the geotechnical ultimate resistance of an anchor and to determine the characteristics of the anchor in the working range in service. The suitability test is a load test to confirm that a particular anchor design will be adequate in particular ground conditions. The acceptance test is a load test to confirm that an individual anchor conforms to its acceptance criteria. Of the three types of tests, only the acceptance test is required for all grouted anchors; the others are specified depending on the particular circumstances presented on the project.

Associated with the test types are three test methods (denoted Test Methods 1, 2 and 3). Test Method 1 involves cyclic tension loading with measurement of displacement at the load stages and Test Method 3 involves step-loading with measurement of displacement under successive maintained tension loads. Although it exists as an option in the standard, Test Method 2 (cyclic tension loading with measurement of load loss) is seldom used in modern anchor practice.

The principle in all grouted anchor testing is that when the anchor is subjected to tensile loading its load vs extension or load loss vs time behaviour is monitored and assessed against acceptance criteria. In Test Method 1, the anchor is loaded stepwise by one or more load cycles increasing from the datum load to the proof load (see Fig. 1). At each load step, the displacement of the tendon is measured during a fixed time period. At the maximum test load or proof load, the creep rate in Test Method 1 is derived from the load vs time data and is used to assess the performance of the anchor installation.

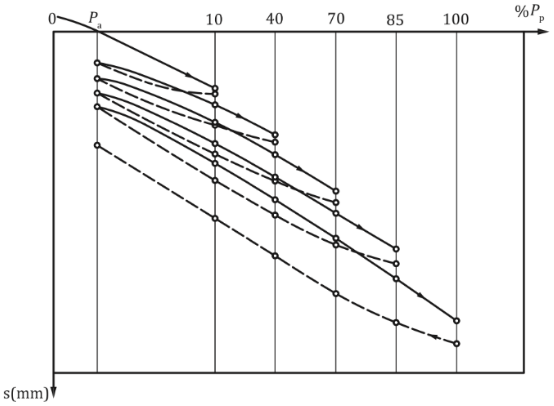


Fig. 1. Example of load-displacement curves for a suitability test on a permanent anchor in coarse soil and rock: P_p is the proof load, P_a is the datum load and s is the tendon displacement (after Figure 8 in EN ISO 22477-5:2018).

AnchorTest facilitates real-time analysis of creep rate (α) at extended observation periods, as per provisions of Annex A of EN ISO 22477-5:2018 (Determination of creep rate α). The estimation of creep rate is required for anchors that exceed the displacement limits for the minimum observation periods specified in

EN ISO 22477-5:2018. The creep rate is derived from the linear portion of a logarithm of elapsed time vs displacement plot at constant anchor load (Fig.2) and is defined by the following formulation:

$$\alpha = (s_b - s_a)/[\log(t_b) - \log(t_a)] = (s_b - s_a)/\log(t_b/t_a) \qquad [1]$$

Where s_a is the displacement of the anchor head at time t_a, s_b is the displacement of the anchor head at time t_b, t_a is the start of the respective time interval, and t_b is the end of the respective time interval.

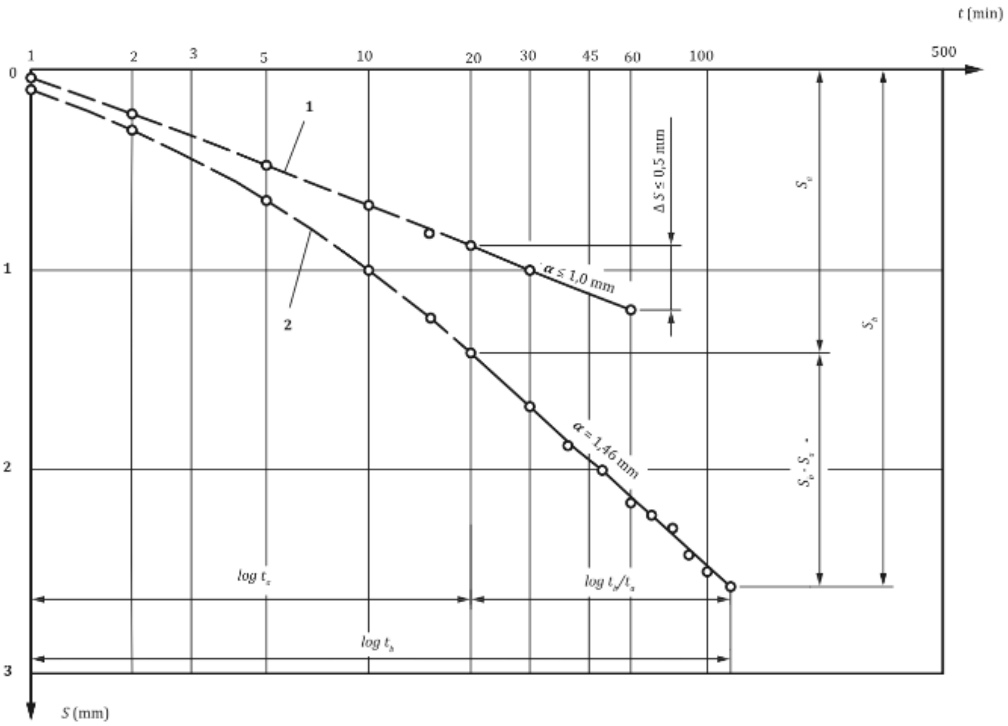


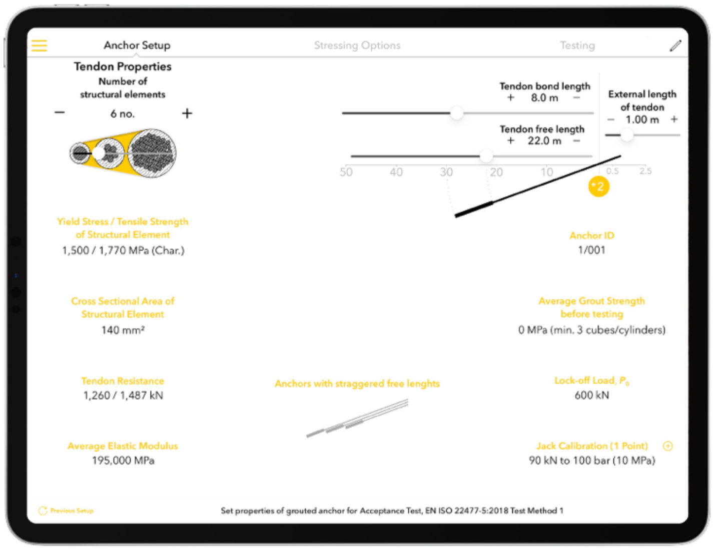
Fig. 2. Example of time-displacement-curves for a suitability test on a permanent anchor in coarse soil and rock: Plot no. 1, Anchor 1 with minimum observation period; Plot no. 2, Anchor 2 with extended observation period (after Figure A.1 in EN ISO 22477-5:2018).

Note that Anchor 2 in Fig. 2 is an example of an anchor that does not fulfil the requirements for the short observation period in Test Method 1, so the observation period is extended to determine the creep rate.

Following the selection of the test type and input of the anchor properties (Fig. 3), and if actual field measurements do not take the form of the idealised curves shown in Fig. 2, the AnchorTest app provides users with two options to rationalize the data:

a) Direct Line: Drawing a line from the last displacement measurement to a selected previous displacement measurement (as early as the third to last point),

b) Interpolation: Linear regression using the selected number of displacement measurement points (a minimum of 3) up to the last one.



Tendon Properties
Number of structural elements
− 6 no. +

Tendon bond length
+ 8.0 m −

Tendon free length
+ 22.0 m −

External length of tendon
− 1.00 m +

Yield Stress / Tensile Strength of Structural Element
1,500 / 1,770 MPa (Char.)

Anchor ID
1/001

Cross Sectional Area of Structural Element
140 mm²

Average Grout Strength before testing
0 MPa (min. 3 cubes/cylinders)

Tendon Resistance
1,260 / 1,487 kN

Anchors with straggered free lenghts

Lock-off Load, P_0
600 kN

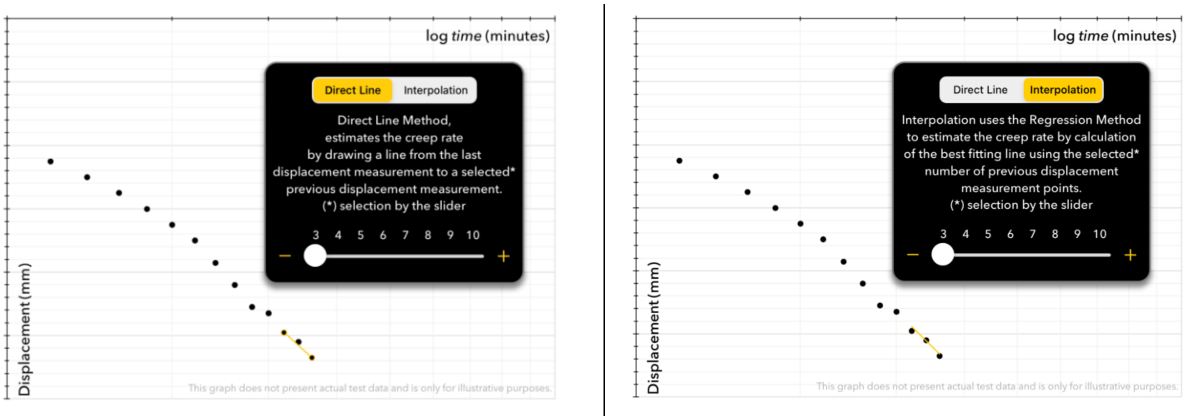
Average Elastic Modulus
195,000 MPa

Jack Calibration (1 Point)
90 kN to 100 bar (10 MPa)

Set properties of grouted anchor for Acceptance Test, EN ISO 22477-5:2018 Test Method 1

Fig. 3. AnchorTest: example input of anchor physical properties.

Fig. 4 illustrates how a set of displacement measurements is processed using the line fitting options.



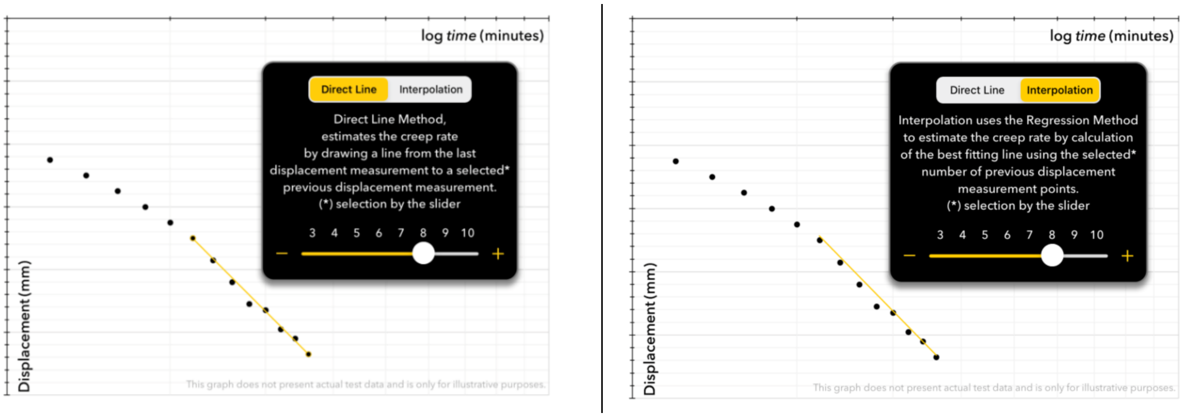
Direct Line Method, estimates the creep rate by drawing a line from the last displacement measurement to a selected* previous displacement measurement.
(*) selection by the slider

This graph does not present actual test data and is only for illustrative purposes.

Interpolation uses the Regression Method to estimate the creep rate by calculation of the best fitting line using the selected* number of previous displacement measurement points.
(*) selection by the slider

This graph does not present actual test data and is only for illustrative purposes.

Fig. 4. User customisation in AnchorTest for the estimation of creep rate using 'Direct line' and 'Interpolation' methods, respectively (3 No. points).



Direct Line Method, estimates the creep rate by drawing a line from the last displacement measurement to a selected* previous displacement measurement.
(*) selection by the slider

This graph does not present actual test data and is only for illustrative purposes.

Interpolation uses the Regression Method to estimate the creep rate by calculation of the best fitting line using the selected* number of previous displacement measurement points.
(*) selection by the slider

This graph does not present actual test data and is only for illustrative purposes.

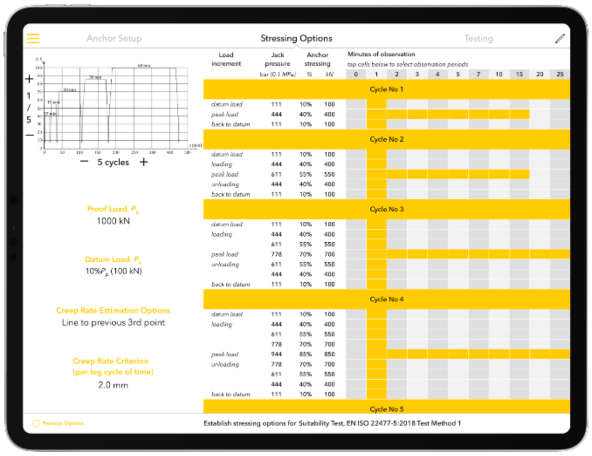
Fig. 5. User customisation in AnchorTest for the estimation of creep rate using 'Direct line' and 'Interpolation' methods, respectively (8 No. points).

The output from each analysis option can be further refined by the user who can opt to customise the data point selection to include previous displacement readings as the start point for the final creep trend line. This selection allows the user the flexibility to apply engineering judgement to the collected data whilst still providing a quick and precise means of estimating the creep rate. Fig. 5 illustrates how changing the number of data points affects the creep rate analysis graph - from 3 (Fig. 4) to 8 (Fig. 5).

Before commencing a suitability or acceptance test, the user is required to configure the creep estimation method in the *STRESSING OPTIONS* screen (Fig. 6). After selection, the app does not permit a change of methodology during testing. This is an intentional design feature of AnchorTest which aims to standardise the conformity criterion during routine testing. Change of the creep estimation method, whilst acquiring the stressing data, is only permitted for Investigation tests due to the investigatory nature of testing (i.e., determining the ultimate geotechnical resistance of the anchor).

Once the stressing operation reaches the peak load at each load cycle, the creep rate analysis panel can be brought to the screen via tap of a button (highlighted in yellow on the analysis summary box as shown in Fig. 7).

The creep rate analysis panel presents previously discussed options and estimates the creep rate together with a graphical representation and an arithmetic formulation. This provides users with a clear and direct way to interpret the collected measurements to derive the linear portion of the log-time vs displacement data. Fig. 8 shows actual creep rate analysis on data derived from a project in Europe.



Proof Load, P_p
1000 kN

Datum Load, P_a
10%P_p (100 kN)

Creep Rate Estimation Options
Line to previous 3rd point

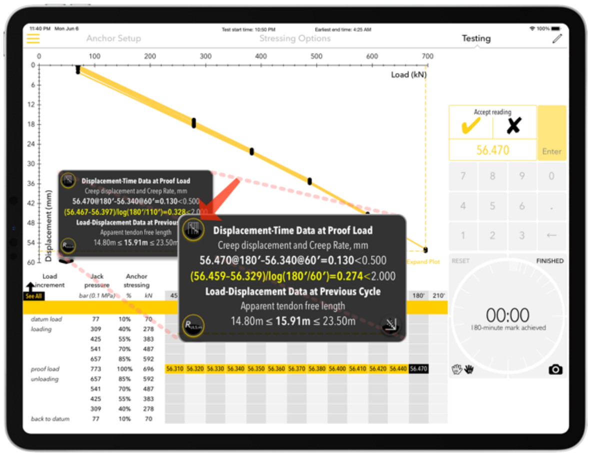
Creep Rate Criterion
(per log cycle of time)
2.0 mm

Load increment	Jack pressure bar (0.1 MPa)	Anchor stressing %	kN
Cycle No 1			
datum load	111	10%	100
peak load	444	40%	400
back to datum	111	10%	100
Cycle No 2			
datum load	111	10%	100
loading	444	40%	400
peak load	611	55%	550
unloading	444	40%	400
back to datum	111	10%	100
Cycle No 3			
datum load	111	10%	100
loading	444	40%	400
	611	55%	550
peak load	778	70%	700
unloading	611	55%	550
	444	40%	400
back to datum	111	10%	100
Cycle No 4			
datum load	111	10%	100
loading	444	40%	400
	611	55%	550
	778	70%	700
peak load	944	85%	850
unloading	778	70%	700
	611	55%	550
	444	40%	400
back to datum	111	10%	100
Cycle No 5			

Minutes of observation
tap cells below to select observation periods
0 1 2 3 4 5 7 10 15 20 25

Establish stressing options for Suitability Test, EN ISO 22477-5:2018 Test Method 1

Fig. 6. Stressing Options screen in AnchorTest for Test Method 1 (EN ISO 22477-5:2018).



Displacement-Time Data at Proof Load
Creep displacement and Creep Rate, mm
56.470@180′-56.340@60′=0.130<0.500
(56.459-56.329)/log(180′/60′)=0.274<2.000
Load-Displacement Data at Previous Cycle
Apparent tendon free length
14.80m ≤ **15.91m** ≤ 23.50m

56.470

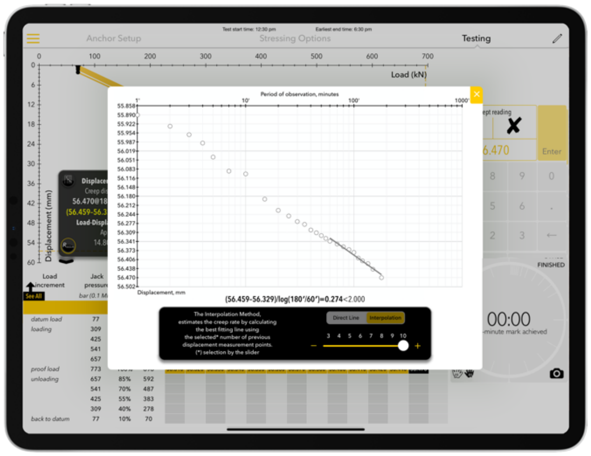
00:00
180-minute mark achieved

Load increment	Jack pressure bar (0.1 MPa)	Anchor stressing %	kN
datum load	77	10%	70
loading	309	40%	278
	425	55%	383
	541	70%	487
	657	85%	592
proof load	773	100%	696
unloading	657	85%	592
	541	70%	487
	425	55%	383
	309	40%	278
back to datum	77	10%	70

45 … 180′ 210′
56.310 56.320 56.330 56.340 56.350 56.360 56.370 56.380 56.400 56.410 56.420 56.440 56.470

Fig. 7. Ongoing testing; analysis box (detail) with estimated creep criteria (EN ISO 22477-5:2018).

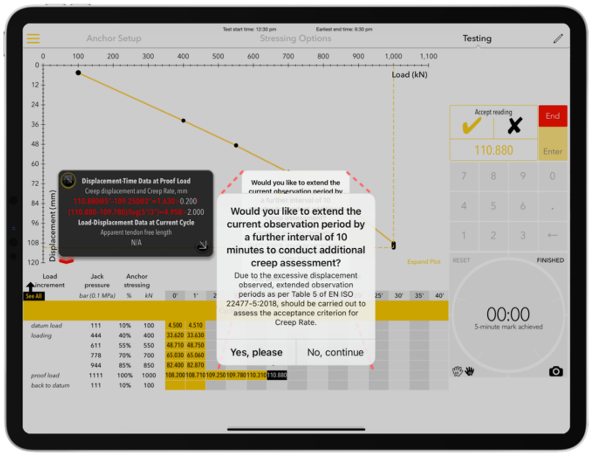
In addition to real-time creep analysis, AnchorTest advises users to extend the minutes of observation if excessive creep displacement is recorded in the short observation period, or excessive creep rate is calculated as per criteria defined in Tables 3 and 5 of EN ISO 22477-5:2018 for Suitability and Acceptance tests, respectively. In cases where excessive creep displacement is observed, users are provided with the option to end the test and create an AnchorTest Cloud record of the data. Fig.9 is a view of the AnchorTest screen during such a scenario.



(56.459-56.329)/log(180′/60′)=0.274<2.000

The Interpolation Method,
estimates the creep rate by calculating
the best fitting line using
the selected* number of previous
displacement measurement points.
(*) selection by the slider

Fig. 8. The creep rate analysis screen in AnchorTest.



Would you like to extend the current observation period by a further interval of 10 minutes to conduct additional creep assessment?

Due to the excessive displacement observed, extended observation periods as per Table 5 of EN ISO 22477-5:2018, should be carried out to assess the acceptance criterion for Creep Rate.

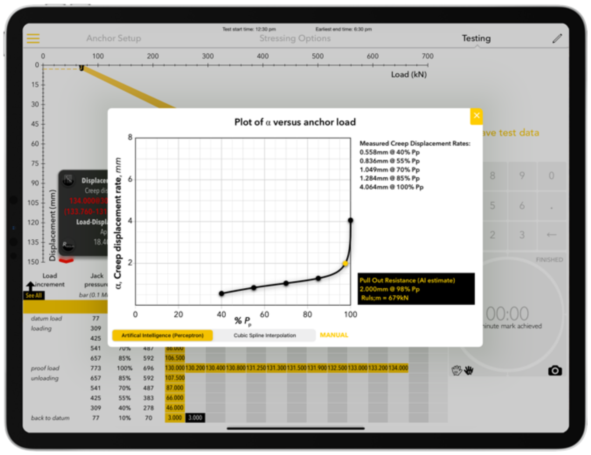
Yes, please | No, continue

Fig. 9. AnchorTest handling a case of excessive creep displacement during routine testing.

At the end of tests with multiple load cycles, where creep rates are analysed and recorded at different load level, AnchorTest will provide a prompt to conduct further analysis of pull-out resistance as per Figure 12 from Clause 8.2.4 of EN 22477-5:2018. If any of the recorded creep rates are higher than the limiting value specified in the national Annex to Eurocode 7 (which is the Creep Rate Criterion set previously on *STRESSING OPTIONS* screen), the app will provide a curve-fitting facility over the measured points and find a corresponding load level for the creep rate criterion. The load level is the measured pull-out resistance. There are two options provided by the app for such curve-fitting exercise:
a) Artificial Intelligence: This method uses a single layer perceptron, which is a feedforward neural network trained with a default set of curve-fitting data.

b) Cubic Spline Interpolation: This method provides uses a more deterministic mathematical approach to quadratic spline curve fitting.

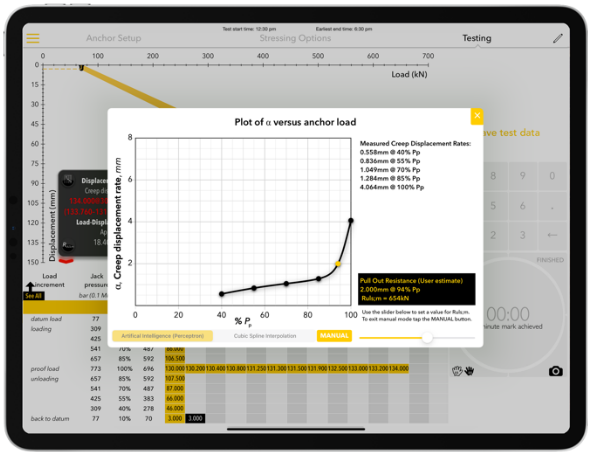
Upon selecting either of these methods, users are provided with an additional option to adjust the inception point for the pull-out resistance allowing for engineering judgement to be part of the process. Fig 10 and 11 show examples for pull-out resistance analysis derived from "Artificial Intelligence"(AI) and manual refinement by user intervention respectively.



Measured Creep Displacement Rates:
0.558mm @ 40% Pp
0.836mm @ 55% Pp
1.049mm @ 70% Pp
1.284mm @ 85% Pp
4.064mm @ 100% Pp

Pull Out Resistance (AI estimate)
2.000mm @ 98% Pp
Ruls;m = 679kN

Fig. 10. Estimation of pull out resistance with the help of AI for curve fitting



Measured Creep Displacement Rates:
0.558mm @ 40% Pp
0.836mm @ 55% Pp
1.049mm @ 70% Pp
1.284mm @ 85% Pp
4.064mm @ 100% Pp

Pull Out Resistance (User estimate)
2.000mm @ 94% Pp
Ruls;m = 654kN

Use the slider below to set a value for Ruls;m.
To exit manual mode tap the MANUAL button.

Fig. 11. AnchorTest allowing user's engineering judgement to refine AI's work

In summary, the AnchorTest module related to EN ISO 22477-5:2018 (Test Method 1) is designed to assist experienced testing technicians and engineers to assess the magnitude of creep displacement, creep rate and apparent tendon free length during routine testing. It permits interrogation of the data points for creep rate and anchor pull-out resistance estimation and conveniently provides line and curve-fitting options to allow timely assessments of anchor performance in the field, or even remotely using instantaneous data sync to the AnchorTest Cloud website.

PTI DC35.1-14 (2014) IMPLEMENTATION

In relation to PTI DC35.1-14 (typically specified in the USA and Canada), the software provides full analyses of both temporary and permanent anchors for Preproduction, Performance and Proof tests, including supplementary extended creep tests, if required. Similar to the European approach, PTI (2014) specifies an acceptance criterion in terms of allowable creep rate per log cycle of time for anchors using bare steel. In the time period of 1 to 10 minutes the creep rate shall not exceed 1 mm (0.40 in), however, if this is exceeded then the creep rate shall not exceed 2 mm (0.80 in). These values are set as default values within the app. It is noteworthy that in the EN ISO 22477-5:2018 module the desired creep rate is set by the user. Additionally, when PTI (2014) is selected the app automatically employs the units appropriate to USA anchor practice (e.g., feet, inches, psi, and kips). However, depending on specification requirements the load vs *movement* plots can be presented in SI units, as well.

BS8081: 1989 IMPLEMENTATION

As previously stated, there are many regions around the world that still specify BS 8081:1989 for anchor testing even though this code has since been superseded by BS8081:2015 +A2:2018. Within BS 8081:1989 two conditions are applied, and the anchor has to satisfy both. Firstly, the anchor performance is judged acceptable if the proof load has not reduced during 15 minutes by more than 5%, after allowing for any temperature changes and movements of the anchored structure. Secondly, if after anchor lock-off, the initial residual load has not reduced by more than 1% per unit of time (5, 15 and 50 minutes extended to 3 hours, 8 hours and 24 hours where appropriate), then the anchor is deemed acceptable. In the absence of common load cell usage, tendon displacement under constant load is conveniently measured using a dial gauge or an appropriately graduated steel rule. The equivalent load change is simply presented to UK clients and engineers by converting tendon displacement using the following:

Load change = (tendon displacement) x (tendon area) x (tendon elastic modulus) / (free tendon length) [2]

AnchorTest incorporates the anchor testing acceptance criteria specified in BS8081:1989 and can present data in the form of load loss or displacement in addition to numerical and graphical representations of the apparent tendon free length. Mothersille and Okumusoglu (2016) describe the use of the BS8081:1989 module for analysing test data derived from ultra-high capacity anchors, with up to 91 No. strand tendons, during the raising of Hazelmere dam in South Africa. Mothersille and Okumusoglu (2017) report on the use of the app for the acceptance testing carried out in accordance with BS8081:1989 on removable single bore multiple anchors used for deep excavation support at the Corniche Towers development in Abu Dhabi, UAE.

CASE HISTORIES

QATAR PETROLEUM MULTI STOREY CAR PARK, DOHA, QATAR – ANCHOR LOAD TESTING TO BS8081:1989

The demolition of Old Qatar Petroleum Head Quarters and the commencement of the enabling works for Qatar Petroleum Multi Storey Car Park at West Bay in Doha started in the first quarter of 2020. The 14 m deep foundation structure, executed by the local branch of Bauer Spezialtiefbau GmbH, comprised a total of 466 secant piles integrated with a lateral support system comprising 900 mm diameter struts for the corner locations and one layer of 141 removable single bore multiple anchors (SBMAs) with working loads ranging from 673kN to 879kN (Fig. 12). The fixed anchors for the SBMAs were located within the stratum described as 'highly weathered Simsima Limestone' with a characteristic UCS value of 6 MPa.

The specification required a design service life of 10 years which meant that although the anchor tendons were to be removed, they were still classified as permanent anchors since the design service exceeded two years. The SBMAs incorporated the classic looped strand system which utilised a double layer of HDPE sheathing to satisfy the requirements of double corrosion protection as recommended in BS8081:2015+A2:2018 (British Standard Code of Practice for Grouted Anchors).

AnchorTest proved itself to be an invaluable tool on this project by permitting real-time assessment of the anchor performance during routine acceptance testing in accordance with BS8081:1989 (Fig.13).

Fig. 12. Overview of the QP Multi-storey car park foundation construction showing lateral support system.

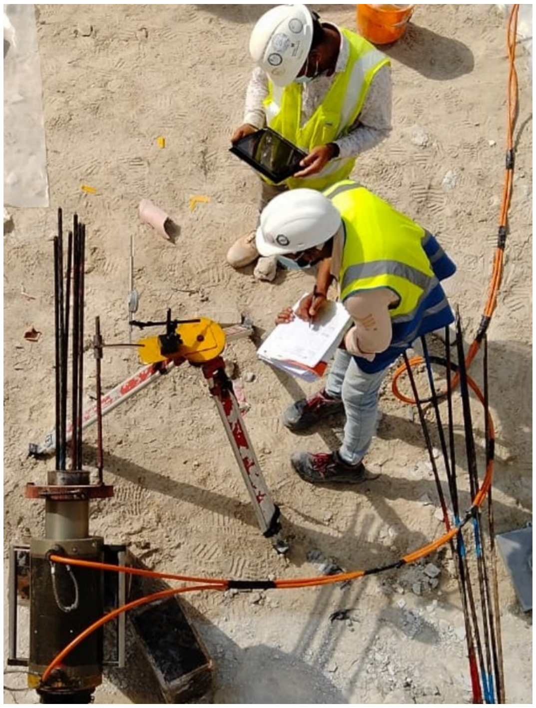


Fig. 13. Routine anchor acceptance testing using AnchorTest on iPad at the QP Multi-storey car park.

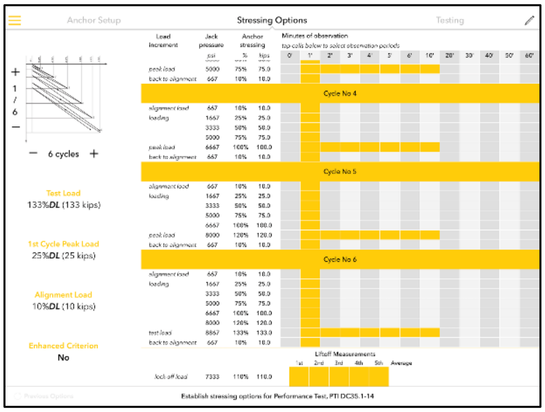
US EMBASSY, MOSCOW, RUSSIA – ANCHOR LOAD TESTING TO PTI DC35.1-14

Mothersille and Okumusoglu (2016) report on the use of AnchorTest during the construction of a new office annex to the US Embassy in Moscow, Russia. The foundation sub-structure was founded in a 13 m deep excavation supported by a secant pile wall and 48 No. permanent mono-bar anchors installed in three rows of 16 anchors. The anchors were installed in mixed soils comprising glacial sand with sandy clay, and morainic deposits of sandy clay.

The decision to use AnchorTest on this project facilitated the anchor construction cycle and tight schedule by providing a means to process data timeously, thereby creating an environment for quick decisions on their performance (Fig.15).

The testing of the anchors was in strict compliance with PTI (2014), thus each anchor was subjected to *Proof* tests up to 133% of the design load. *Performance* tests, with lift-off checks, were also required for two anchors at each anchor level (see typical app generated *STRESSING OPTIONS* screen in Fig. 14).

Fig. 14. AnchorTest usage for routine acceptance testing in Moscow, Russia.



Test Load
133%*DL* (133 kips)

1st Cycle Peak Load
25%*DL* (25 kips)

Alignment Load
10%*DL* (10 kips)

Enhanced Criterion
No

Minutes of observation
tap cells below to select observation periods
0' 1' 2' 3' 4' 5' 6' 10' 20' 30' 40' 50' 60'

Load increment	Jack pressure psi	Anchor stressing %	Anchor stressing kips
peak load	5000	75%	75.0
back to alignment	667	10%	10.0
Cycle No 4			
alignment load	667	10%	10.0
loading	1667	25%	25.0
	3333	50%	50.0
	5000	75%	75.0
peak load	6667	100%	100.0
back to alignment	667	10%	10.0
Cycle No 5			
alignment load	667	10%	10.0
loading	1667	25%	25.0
	3333	50%	50.0
	5000	75%	75.0
	6667	100%	100.0
peak load	8000	120%	120.0
back to alignment	667	10%	10.0
Cycle No 6			
alignment load	667	10%	10.0
loading	1667	25%	25.0
	3333	50%	50.0
	5000	75%	75.0
	6667	100%	100.0
	8000	120%	120.0
test load	8867	133%	133.0
back to alignment	667	10%	10.0
lock-off load	7333	110%	110.0

Liftoff Measurements
1st 2nd 3rd 4th 5th Average

Previous Options

Establish stressing options for Performance Test, PTI DC35.1-14

Fig. 15. AnchorTest: Stressing Options screen (PTI, 2014).

For all anchors, plotting of proof test data (load vs *movement*, Fig.16), graphical analysis of proof test data (apparent free tendon length estimation) and the elastic vs plastic *movement* assessment, was conducted with AnchorTest to provide analyses in real-time as testing progressed (Fig. 17).

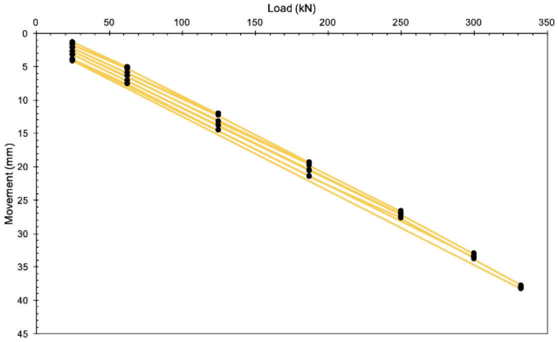


Fig. 16. AnchorTest: Load vs Movement plot in real-time (PTI, 2014).

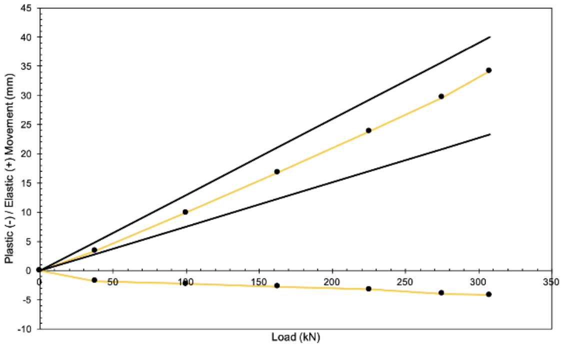


Fig. 17. AnchorTest: Elastic and Plastic Movement (PTI, 2014).

Test records were made directly accessible to the quality control department of the general contractor. Anchors were finally locked-off, at the latest by the next workday, following on-site testing. This was all made possible with the cross-platform AnchorTest Cloud component built into the AnchorTest software, linking it to the AnchorTest Cloud website.

AnchorTest enabled the specialist anchor contractor to *proof* test, lock-off and hand over the anchored section of the excavation on time and within budget with reduced engineering and administrative staff input, due to automated and real-time data analysis, together with instant and paperless distribution of compliance reports. The representatives of the Owner and the Engineer were particularly satisfied with the additional innovation introduced by the use of AnchorTest in realising this challenging project.

SUMMARY AND CONCLUSIONS

AnchorTest is a unique tool that has been successfully implemented in major anchor works in a number of regions including Europe, Russia, South Africa, United Arab Emirates, Qatar and the USA.

The software has proved effective in optimising the process of anchor testing. It is currently programmed to execute data analysis in accordance with PTI DC35.1-14, BS8081:1989 and the International Organization for Standardization EN ISO 22477-5:2018 (Test Method 1). The software uses a unique and intuitive user interface and incorporates facilities for interrogating load vs displacement and displacement vs time data to derive the creep rate of the anchor. Creep rate is now extensively used as one of the parameters for which anchor performance is assessed against established criteria for acceptance and failure.

A crucial feature is the Cloud back-end database that permits any nominated third party to scrutinise the data and analysis remotely. This means that as work progresses on site, decisions can be made quickly and delays in anchor construction avoided. The digitised records produced from the app are conveniently placed within the QA/QC protocols that are established on the project and can be easily extracted for reporting purposes, maintenance strategies and future review.

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