UNIVERSITÉ DE SHERBROOKE

Creep testing of AMBEX AAC anchoring capsules

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1 INTRODUCTION

This report presents the experimental results obtained under the research project *Optimizing the performance of a cementitious anchoring grout for anchors in concrete - Study of creep and the influence of grout properties and behavior of anchoring systems*. This research projects was conducted in partnership with AMBEX Concrete Technologies Inc. and Sherbrooke University, Department of Civil Engineering and is funded by a 24,420 $ grant from NSERC (Natural Science and Engineering Council of Canada).

This report presents an analysis of creep behavior results obtained from a set of 5 tests on concrete anchors.

2 EXPERIMENTAL PROCEDURE

2.1 Testing equipment setup for sustained loading

Figure 1 shows a loading frame used for tensile tests for sustained loading of anchors. This experimental device is an adaptation of a test apparatus developed by Prof.B. Benmokrane for the study of creep under tension in composite materials bars. For this project, a group of five frames was constructed and commissioned in March 2011.

The frames are built mainly with HSS square section tubular steel. It works on the principle of a double lever (main and secondary) which can multiply by a factor of about 70 the force of the weight of concrete blocks placed on a hanger at the end of the secondary lever (Figure 1). The upper right end of the main lever (Figure 1) is connected to a steel rod that is used as a calibrated load cell to measure the tensile force applied to the anchor. The upper end of the steel rod is connected to a ball joint which allows free rotation of the end of the lever. Both ends of the calibrated rod are threaded to allow precise adjustment of the horizontality of the main lever arm. The test set-up conforms to the requirements of ASTM - E 1512 (*Evaluation of anchors in concrete under sustained loading conditions*).

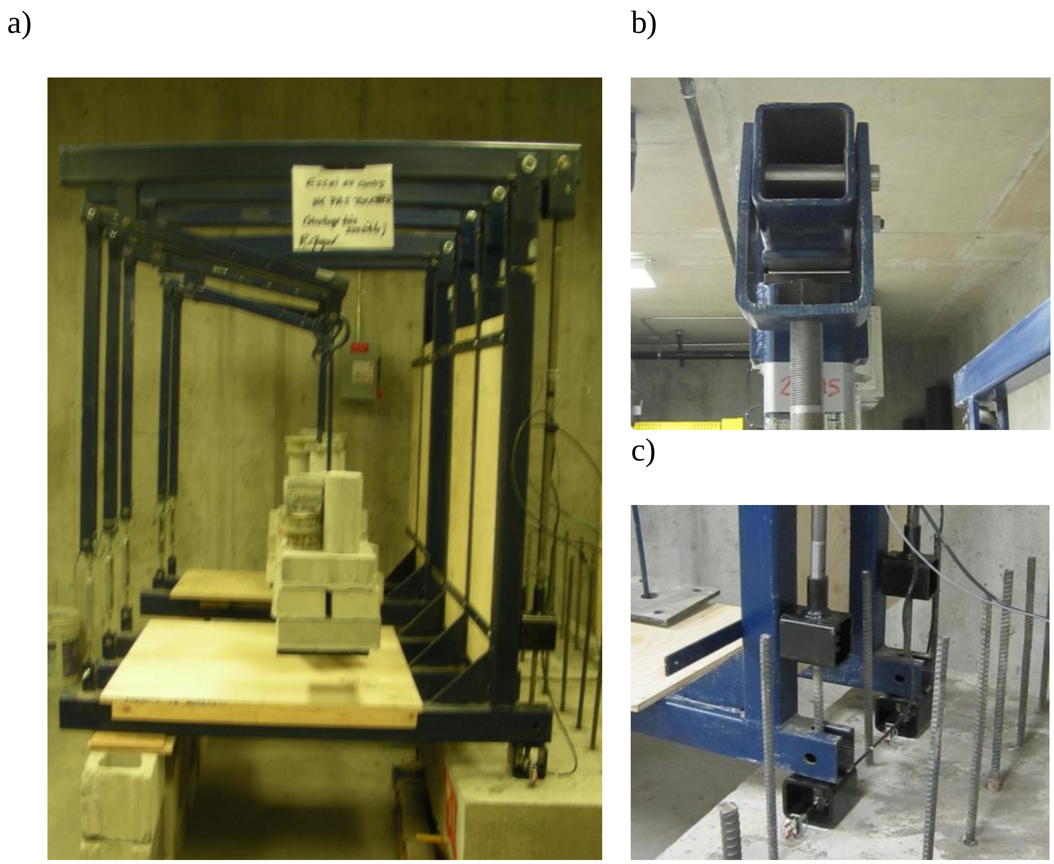

Figure 1. a) Test setup   b) Upper rod connection c) Lower anchor connection

The test frame applies a sustained load on a rebar anchored in concrete for specified period of time (6 weeks). The tensile force applied to the anchor is measured with four electrical strain gauges (full bridge) attached on the calibrated vertical rod connecting the end of the main lever to the end of the anchor (Figure 2). The rod is connected to an automated data acquisition system which records the load every second. The load can be measured to an accuracy of ± 0.1 kN.

Two linear motion position sensors (BEI-Duncan 9600) are used to measure the displacement of the anchor rod (Figure 2).These sensors are located about 30 mm above the concrete surface. Both sensors are electrically connected together so that a single electrical signal measures the average movement of the sensor pair (tandem). The accuracy of the displacement measured by a tandem is ± 10 microns.

a) b) c)

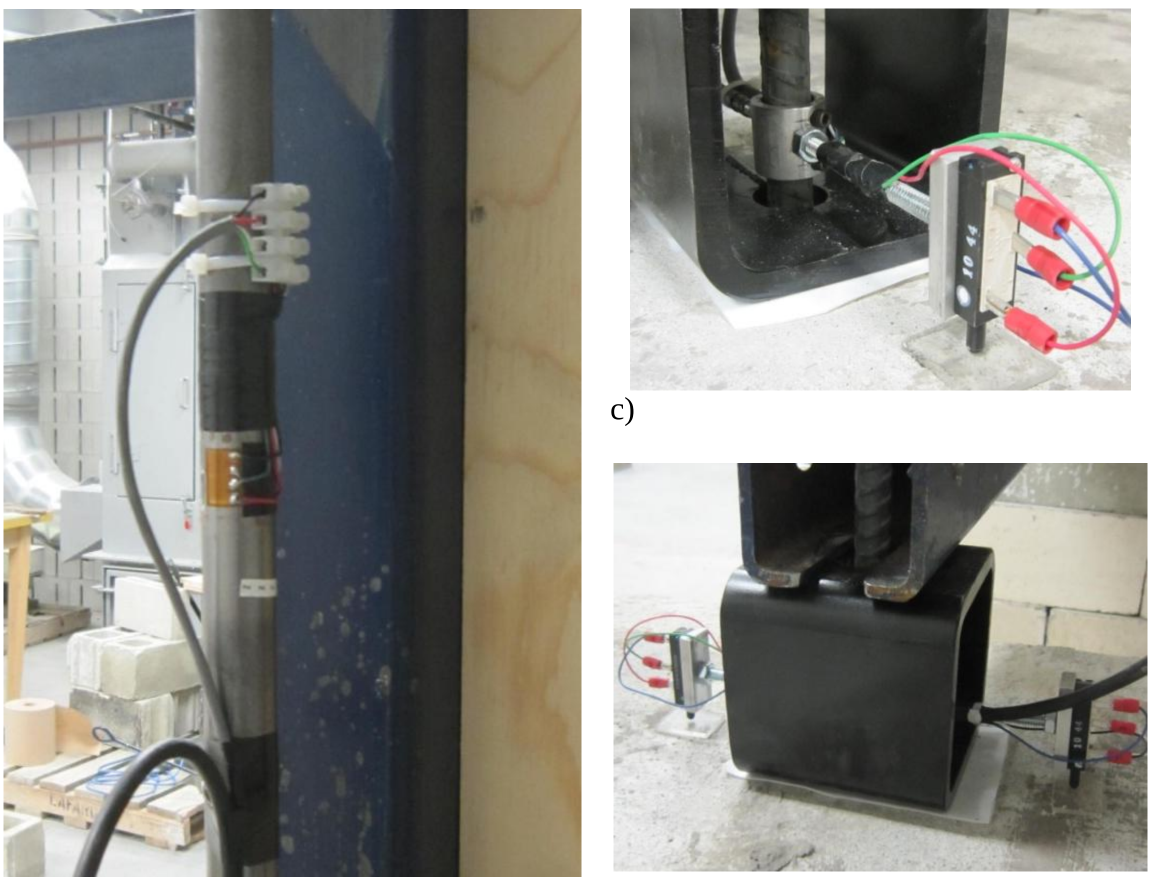

Figure 2. a) Strain gauges and displacement transducers b) Sensor details c) Displacement sensor setup

2.2 Data acquisition system

Data acquisition is done using a VISHAY System 5100B (Figure 3). The system reads and displays the load (kN) and displacement of the anchor rod (microns) once per second. The date, time, load and displacement are recorded once every 15 minutes. The system is automatic and a complete backup of all data is done every 12 hours. This procedure avoids an extended power outage resulting in the loss measurements during a period of up to 12 hours.

Figure 3. VISHAY System 5100B data acquisition system

2.3 Calibration of the load cells and the displacement sensors

The calibration of the measuring instruments (load cell, displacement transducers and calibrated tensile rod) was done with the system Vishay 5100B System. The calibration of each rod was performed using a tensile testing machine, MTS 810. (Figure 4).

Each transducer tandem setup was calibrated using a micrometer calibration bench specially designed for this application (Figure 4). The micrometer has a resolution of ± 1 micron.

The load cell (Tovey Engineering model 2134-200k - 200 klbs), Figure 5, was calibrated with a hydraulic press in the concrete laboratory of the Sherbrooke University.

a) b) c)

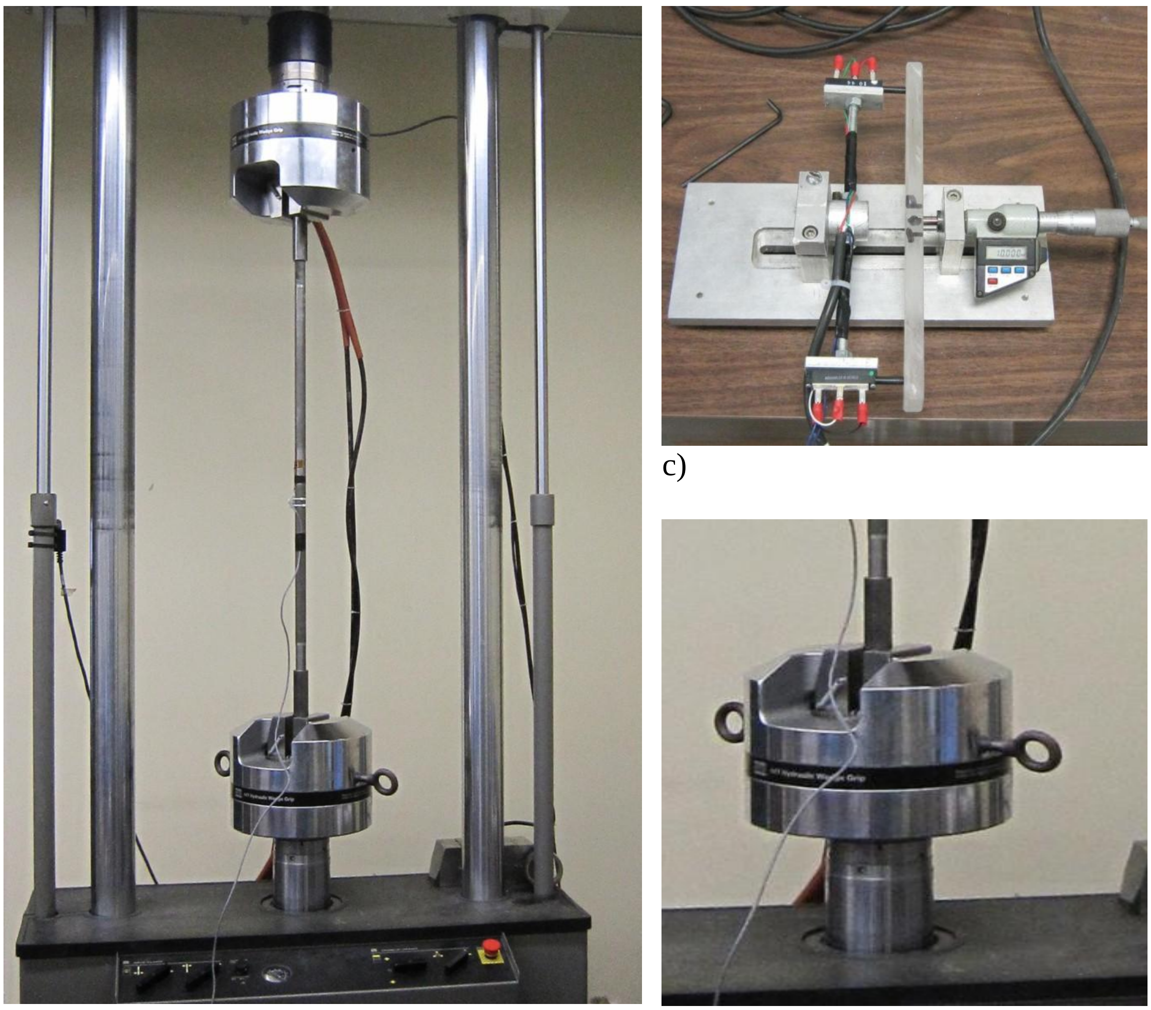

Figure 4. a) Calibration of tensile rods using the MTS tensile machine b) Calibration setup for displacement traducers c) Lower connection arrangement

3 TESTS

Three types of tests were performed at this stage of the project. A direct tensile test was performed on a series of five 15M reinforcing steel bars. Two types of loading test (static loading and sustained) were conducted on two series 5 rebars embedded 20 cm in a concrete slab. The steel grade was 400 MPa for all tests. The cementitious anchoring material was AMBEX AAC anchoring capsules. The temperature of the test room was maintained at 23 ± 3 ° C.

3.1 Direct tensile test

The Rebar (15M) used for the anchors were subjected to direct tension test using an MTS 810 testing machine. The purpose was to measure the yield and ultimate tensile strengths of the rebar. The test consisted of applying a tensile load on a series of 5 individual rebar. The elongation and the load were measured continuously and simultaneously. Each tensile test was carried out until the tensile failure of the bar.

3.2 Static load test

The static load tests measures the tensile strength of the anchoring system under a short duration loading (3-5 minutes). The test was performed on 5 bars. The tensile load was applied with a portable hydraulic pump ENERPAC, a center hole hydraulic jack and a load cell connected to a data acquisition system (VISHAY 5100B). Figure 5 shows the static load testing setup. The pump flow is adjusted to control the strain rate imposed on the anchoring system. This rate is fixed so the pullout of the bar occurs after 2 ± 1 minute. All baseline static load tests are restrained (confined) tests.

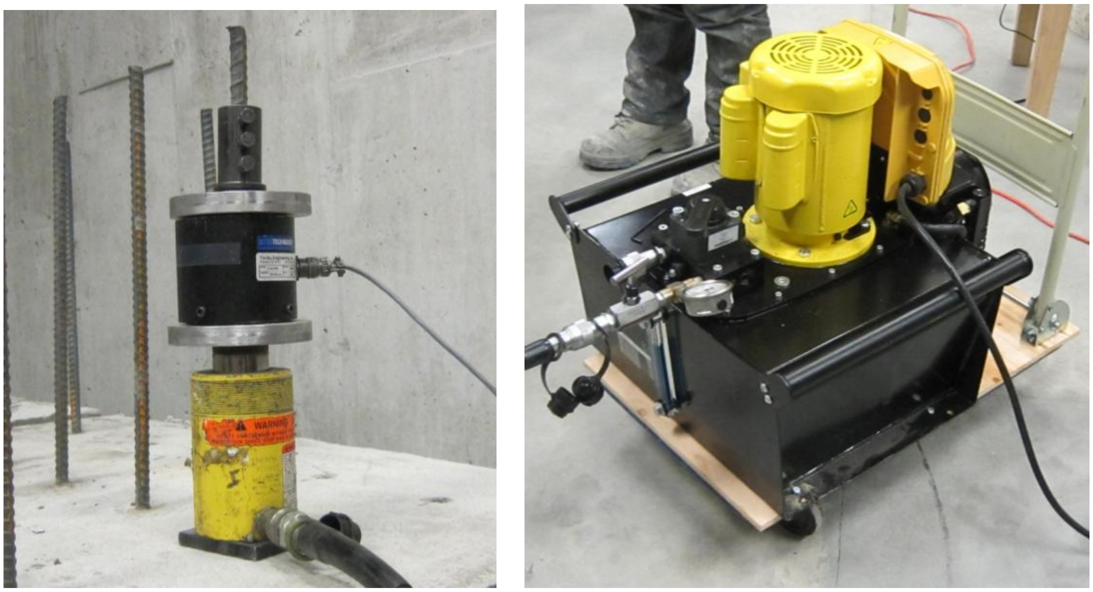

Figure 5. Static load testing setup

3.3 Sustained load

Sustained load tests were conducted with the test frame described in Section 2.1 (Figure 1). A sustained load was applied for 42 days. The percentage of the ultimate load required in ASTM E-1512 is 40% of ultimate pullout load. In this test we opted for 55% of yield load as determined by static testing. All baseline sustained load tests were restrained (confined) tests.

4. RESULTS

4.1 Tensile testing of rebar

Table 1 and Figure 6 present the results of tensile tests on 15M rebar loaded until failure. The bars are not anchored in a concrete base.

The mean values (Table 1) indicate that the initial yield load is 81 kN, representing a yield stress of 401 MPa. The ultimate strength (failure) is 125 kN.

Table 1. Results of direct tensile tests

Rod #	Yield load (kN)	Yield Strength (MPa)	Ultimate load (kN)
1	81	401	124
2	81	404	123
3	80	400	120
4	81	402	120
5	81	400	135
Average	**81**	**401**	**125**

Figure 6 shows a typical load-displacement curve obtained during the direct tensile test (Rod #1). Note that the elastic zone of the rebar is below 81 kN. Beyond this load (81 kN), there was a short plateau followed by plastic and hardening zones. The rupture occurred at 124 kN. Theses curves are typical behavior for rebars steel.

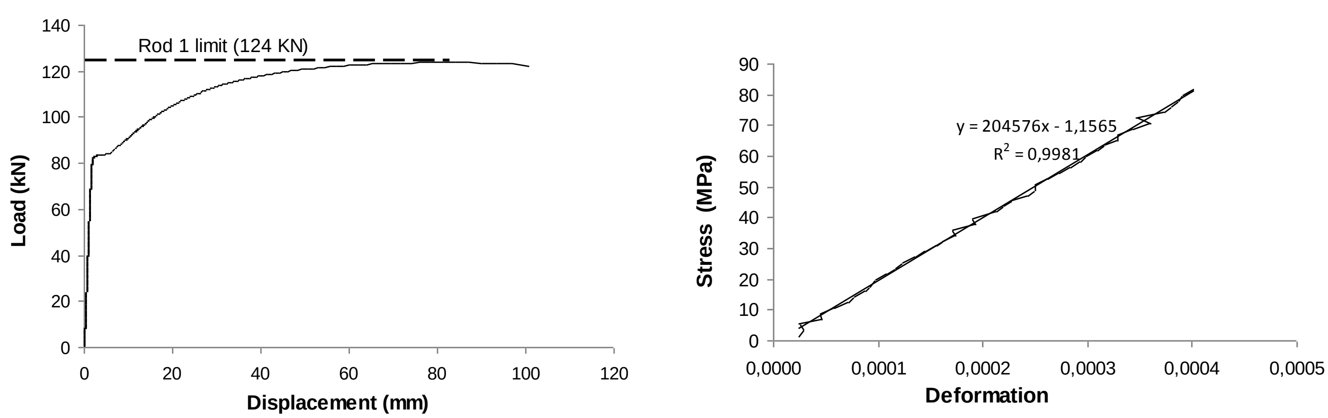

Figure 6. Direct tensile results on 15 M rebar (rod #1)

4.2 Static load test on anchoring system

Table 2 presents the results of a tensile load test of short duration on a group of five anchors. Figure 7 shows a typical curve of the load applied as a function of time measured for the duration of the test (Rod #4). The first linear portion (below 81 kN) shows the elastic behavior of the bar. The yield stress measured with the pullout test is the same as that measured with the direct tension test (Section 3.1 and Table 1). Beyond the elastic limit, there is a small plastic deformation, followed by a hardening phase of the rebar leading to the complete failure of the anchor system (119 kN). Overall, this curve is very similar to the curve obtained in direct tensile tests. This concurrence confirms the validity of the measurements made during the loading. The average of pullout load of 5 tests is 109 kN.

Table 2. Results of pullout tests (Static Load)

	Rod 1	Rod 2	Rod 3	Rod 4	Rod 5	Average
Maximal load (kN)	118	115	117	119	78	109
Yield load (kN)	83	79	76	81	71	78

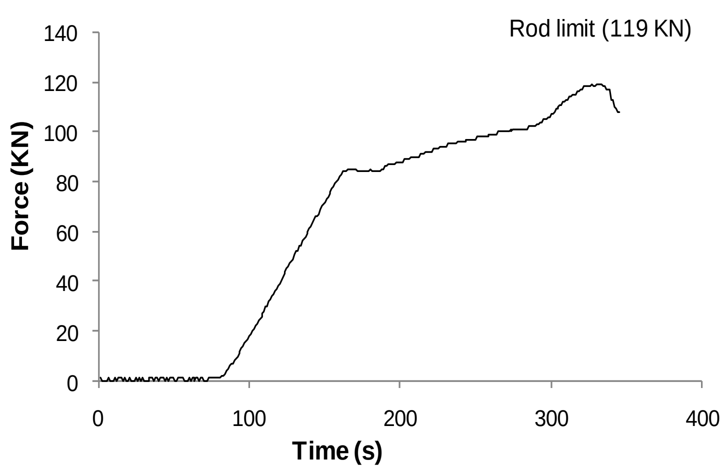

Figure 7. Results of the static pull test (Rod 4)

Analysis of the load evolution over time (Figure 7) shows that the full elastic capacity (81 kN) of the steel rod has been achieved with the AMBEX AAC anchoring system. Overall, the cementitious material anchoring system shows a high ductility at rupture. It is the mechanical properties of steel that control the failure and not those of the anchoring system in the concrete substrate.

4.3 Sustained load test on anchoring system

Figure 8 shows a typical load - displacement curve during the initial loading, just before the start of a sustained load test. Sustained load tests are performed using a tensile force of 45 kN, corresponding to 55% of the first yield load of the anchoring system. In this report, the first yield load of the anchoring system is the elastic limit of the steel bar (81 kN).

The black curve shows the evolution of the tensile force applied on the anchoring system as a function of time. This force (kN) was measured using the calibrated steel rod. It took about 10 minutes to load up the concrete blocks on the hanger to produce exactly a load of 45 kN corresponding to 55% of the elastic limit of the anchoring system. During the loading process, some blocks were removed then replaced on the platform. The load variations generated during this process are clearly visible on the black curve.

The red curve shows the evolution of the displacement of the anchoring measured using tandem displacement sensors. This measure is the vertical displacement at the attachment point of the tandem on the anchor rod. This point is located approximately 3 cm above the concrete surface. The red curve shows that the displacement varies simultaneously with the tensile force applied to the anchor. It roughly corresponds to the elastic deformation of steel and the anchoring system below the attachment point of the transducers. Once the final loading of 45 kN is achieved, the initial measured displacement is about 200 microns. Overall, the curve shows the high sensitivity of the displacement measuring system. As mentioned previously, the measurement accuracy is about ± 10 microns.

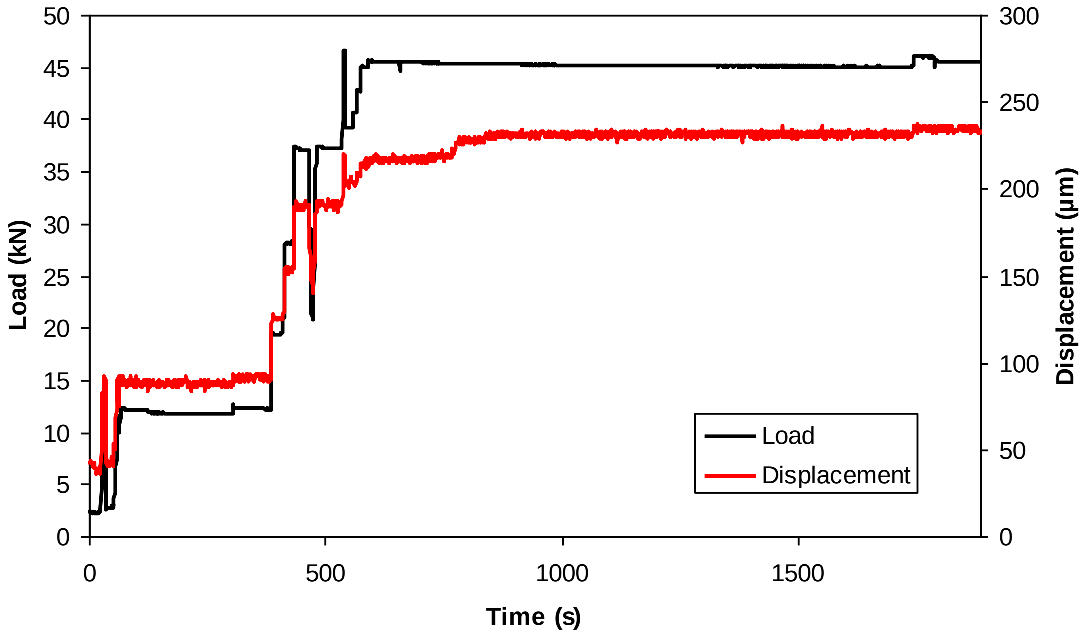

Figure 8. Typical load - displacement curve during the initial loading, just before the start of a sustained load test

Figures 9-13 show the results of a series of 5 tests on 15M rebar anchored 200 mm in concrete under sustained loading. Each figure shows the evolution over time of the load on the anchor (black curve) and the displacement of the anchoring system measured on the steel rod at 30 mm above the concrete surface (red curve). The origin of the time axis (time = 0) is immediately after reaching the load of 45 kN (Figure 8). At this time, the displacement has been reset to 0 microns to better visualize its evolution over time.

Figure 9 (Rod #1) shows that the load is constant over time, confirming that the test frames can maintain a load of 45 ± 1 kN over a long period of time. After about 24 days, Figures 9-13 indicate that the load slowly decreased to 44 kN. This variation was observed for all 5 frames. This small load decrease is attributed to a slight drop in the room temperature (about 3 º C) where the testing apparatus were installed. This drop in temperature caused a slight contraction of the steel parts (including the calibrated rod) which resulted in a slight reduction of the force. Additional weight was added to platform to increase load to 45 kN.

After 42 days, the curves show that under a constant load of 45 ± 1 kN (55% load of elastic limit of the rebar), the vertical displacement at the base of the anchors is in the 0 to 20 micron range. These small changes, within the precision limit of the displacement transducers, indicate that there is practically no creep and no sign of damage of the anchoring system.

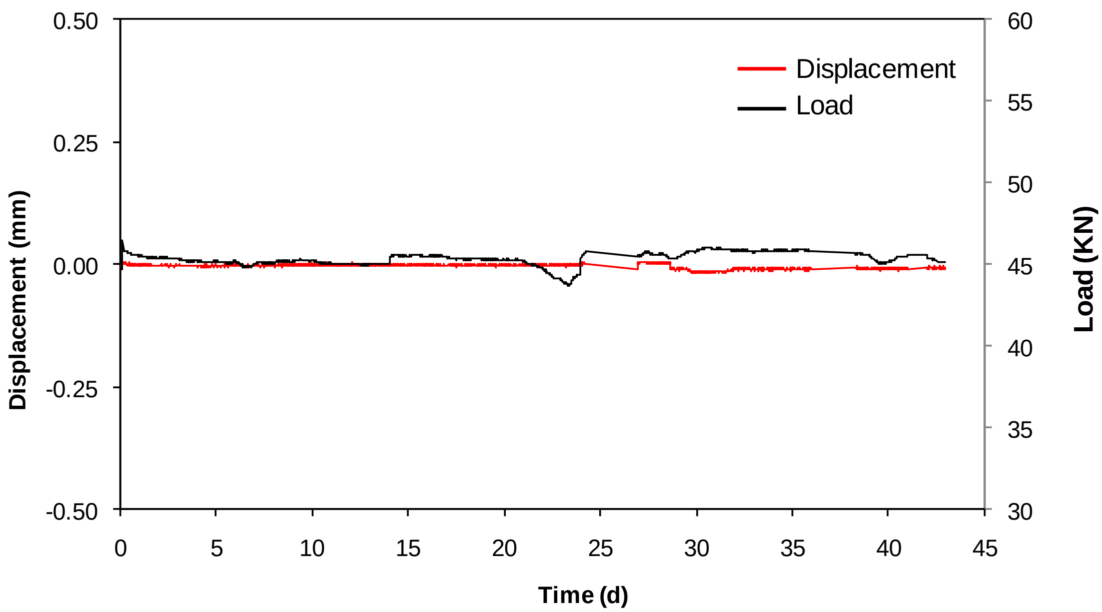

Figure 9. Results of sustained load test (displacement and load vs time) for anchor #1

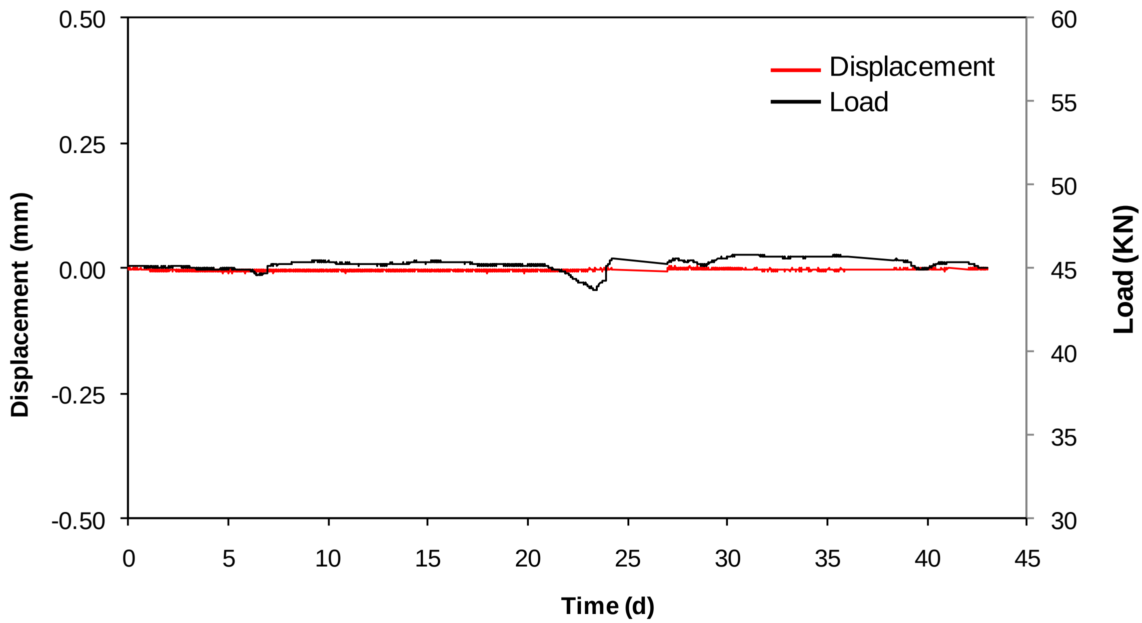

Figure 10. Results of sustained load test (displacement and load vs time) for anchor #2

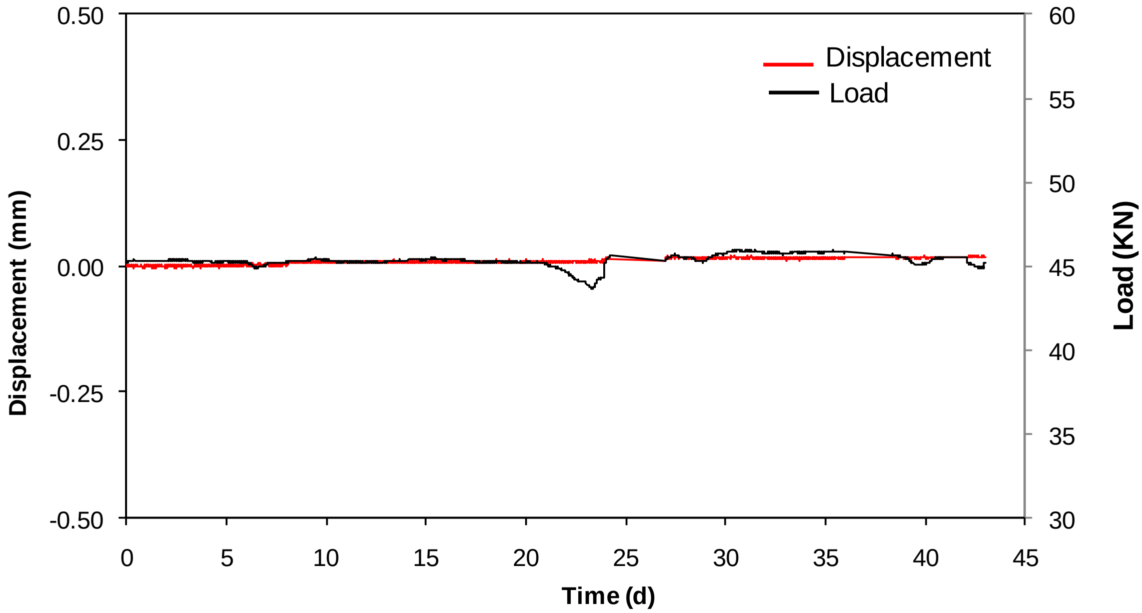

Figure 11. Results of sustained load test (displacement and load vs time) for anchor #3

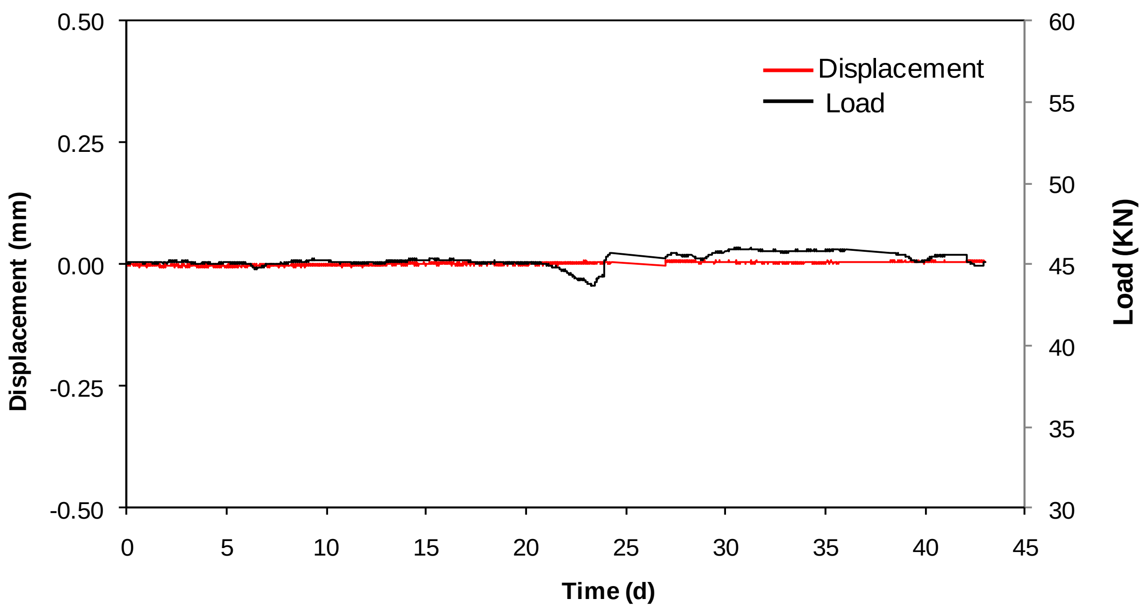

Figure 12. Results of sustained load test (displacement and load vs time) for anchor #4

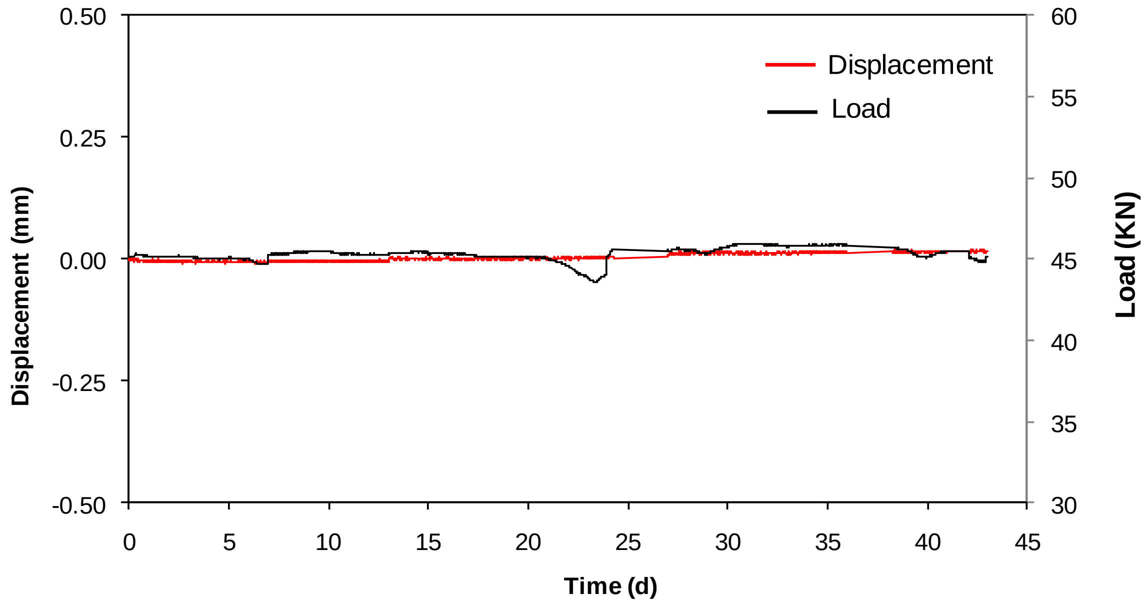

Figure 13. Results of sustained load test (displacement and load vs time) for anchor #5

5 CONCLUSIONS

The following conclusions based on the results of this research project are presented herein:

- An experimental testing procedure and apparatus were developed and calibrated to accurately measure the long term creep of a post-installed cementitious anchoring system for rebar installed in concrete. The testing equipment developed meets the requirements of *ASTM E1512 – Evaluation of anchors in concrete under sustained loading conditions.*

- The testing apparatus can measure a sustained load with a precision of ± 0,1 kN. It can also accurately measures the displacement of the bar with a precision of ± 10 µm.

- A cementitious anchoring system using AMBEX AAC anchoring capsules was used to install 2 sets of 5-15M rebars with an embedment length of 200 mm in concrete. Static load tests were performed on the first series of 5 rebars until pullout was achieved. The results show that AMBEX AAC anchoring capsules are able to develop the full mechanical capacity of the rebar prior to its yielding (followed by necking and failure of the anchoring system).

- The failure of the anchoring system reflects the ductile behaviour of the system and is essentially linked to the elastic-plastic properties of the 15M rebar

- After 42 days, the curves show that under a constant load of 45 ± 1 kN (55% load of elastic limit of the rebar), the vertical displacement at the base of the anchors is in the 0 to 20 micron range. These small changes, within the precision limit of the displacement transducers, indicate that there is no creep, after 43 days, and no sign of damage of the anchoring system