UNIVERSITY OF DUNDEE

Division of Civil Engineering

Chun Qing Li, BE, MSc(Eng), PhD, MIEAust, CPEng
Specialised in Risk Assessment, Whole Life Analysis, Corrosion Effects and Concrete Design
Direct contact: Phone - 44 1382 344345, Fax - 44 1382 344816, Email - c.q.li@dundee.ac.uk

4 May 2005

Mr J McDonald
General Manager
Cementaid Ltd
1 Baird Close
Crawley
West Sussex, RH109SY
England

Dear James

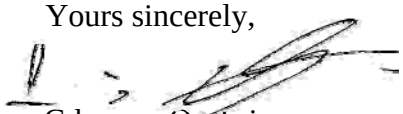
RE: LONG TERM TEST OF RC WALLS WITH EVERDURE CALTITE SYSTEM

Please find the closed final report of the project *Long Term Test of RC Walls with Everdure Caltite System.*

At the completion of the project I like to thank you sincerely for giving us the opportunity to carry out this exciting research work.

I look forward to more collaborative work with you in the future.

Yours sincerely,



C h u n Q L i
Senior Lecturer

CORROSION RESISTANCE OF CONCRETE STRUCTURES MODIFIED WITH EVERDURE CALTITE SYSTEM

Prepared for:

Mr James McDonald
Cementaid (UK) Limited
2 Rutherford Way
Industrial Estate
Crawley
West Sussex, RH10 9LN
England

Prepared by:

Dr Chun Q Li
Senior Lecturer
University of Dundee
Dundee, DD1 4HN
Scotland

Submission date: 23 December, 2004

SUMMARY

Cementaid (UK) Limited commissioned University of Dundee to conduct experimental research on corrosion resistance of concrete structures modified with Everdure Caltite. The primary objective of the experiment is to quantify the corrosion resistance of concrete structure as measured by the load carrying capacity of the structure.

Based on experimental results it can be concluded that

- Concrete structures with Everdure Caltite admixture out-perform those with ordinary Portland cement concrete by all available measures.
- Corrosion does not initiate in concrete structures with Everdure Caltite admixture until after about 26 years, compared with just 6 months for those with ordinary concrete
- Corrosion in concrete structures with Everdure Caltite admixture only reduces the load carrying capacity of the structures by 2% in about 50 years.

FINAL REPORT

Introduction

Everdure Caltite System is a two-component concrete admixture which incorporates a hydrophobic and pore-blocking ingredient to provide waterproof concrete. Launched as a new product in 1958 by Cementaid, Everdure Caltite has traditionally been used as a concrete admixture for the purpose of waterproofing. Thus far Everdure Caltite has been used in over 10 million cubic metres of concrete and received a BBA Certificate (No. 93/2888).

The greatest potential of Everdure Caltite is, however, to protect reinforcing steel bars from corrosion in concrete structures located in corrosion prone environments, such as marine environment. It is therefore desirable that research be carried out in a systematic manner to investigate the corrosion resistance of concrete structures modified with Everdure Caltite system as measured by load carrying capacity.

It is in this regard that Cementaid (UK) Limited commissioned University of Dundee to conduct experimental research on corrosion resistance of concrete structures modified with Everdure Caltite. Details of the research contract to undertake the experiment are attached as Appendix A.

Objectives

The primary objective of the experiment is to quantify the corrosion resistance of concrete structures modified with Everdure Caltite admixture to be measured by load carrying capacity of the structure. Both the initiation and propagation of corrosion in the Everdure Caltite modified concrete will be monitored. The experiment also investigates how Everdure Caltite admixture improves the corrosion resistance of concrete structures, using concrete structures with ordinary Portland cement concrete as reference.

Test methodology

Test specimens. The specimens tested were concrete walls, which were designed in accordance with British Standards: BS 8110: 1997, BS. The dimension of specimens is 1000 x 2000 x 150 mm which was determined based on the size of the test facility available, i.e., the environment chamber. The concrete was made of Portland cement, supplied by a ready mixed concrete company. The addition of Everdure Caltite admixture was supervised by Cementaid. There were a total of 5 specimens; one tested at the beginning (for intact capacity) and two each tested at 8 and 16 month respectively after being exposed to saltwater spray - simulating marine environment.

All specimens were subjected to simultaneous service load, which is about 60% of the nominal capacity of the specimens (concrete walls). The specimens were supported at one end on a concrete foundation to form a cantilever. The primary and secondary reinforcement used in the walls were determined according to BS 8110 and shown in Table 1.

Table 1 Details of the section of the specimens

Cover	Main reinforcement			Secondary reinforcement		
	As (mm^2)	ρ (%)	Rebar	As (mm^2)	ρ (%)	Rebar
30 mm	471	0.41	6T10	195	0.17	4T10

Test Facility and Setup. To simulate the working conditions of marine structures, a large environmental chamber was constructed to house the specimens. As schematically shown in Figure 1. two pipes with spray heads are hung on each side of the chamber to wet the specimens. A pair of test specimens is loaded through two rods. This set-up simulates sea-walls in service.

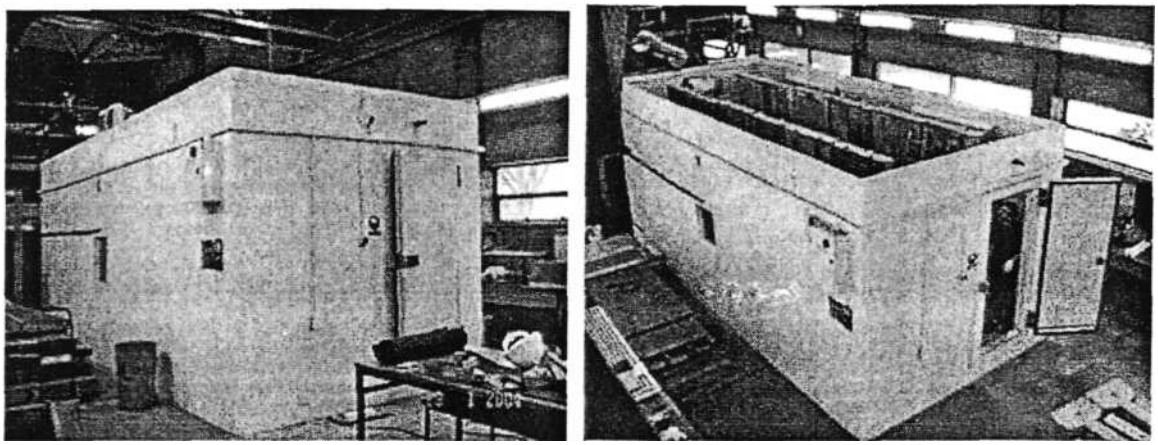


Figure 1 Large environmental chamber

All specimens were under the same simulated conditions for the corrosion process. A typical day of test conditions for the corrosion process is shown in Table 2. The concentration of salt solution used in the spray was 3.5% (by weight) sodium chloride (NaCl), which represents typical seawater.

Table 2 A typical day of test conditions

Hours	Spray of NaCl solution	Temperature	Relative Humidity	Note
1-4	4 hours on	10°C (water)	N.A.	Wetting
4-12	8 hours off	30°C	50%	Drying
12-16	4 hours on	10°C (water)	N.A.	Wetting
16-24	8 hours off	30°C	50%	Drying

Measurements. Half Cell Potential **(HCP)** is the most useful measurement to assess the corrosion condition in practice. To measure HCP, a high impedance voltmeter and a probe (reference electrode) were used.

The linear polarization resistance (LPR) was measured to monitor the corrosion progress in the concrete. LPR was then converted to corrosion current density which is a measure of corrosion rate. The equipment used is potentiostat.

The cross-sectional area of the corroded section of the reinforcement bars was measured by taking out the corroded bars from concrete after the loading test. ASTM standard procedure was used for the measurement.

Loading test. To investigate the corrosion effect on structural capacity deterioration it is necessary to carry out destructive loading tests on specimens after exposure for certain period of time. Figure 2 shows the setup of the destructive loading test.

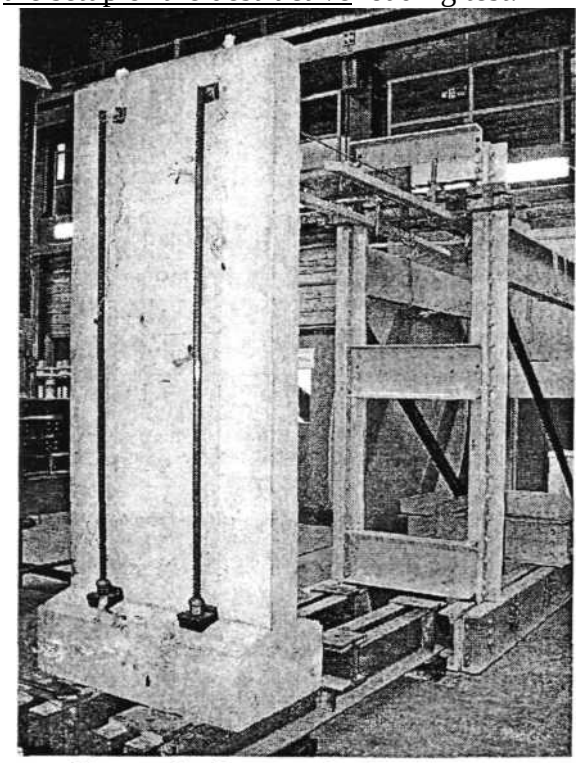


Figure 2 Destructive loading test

Test Results and Analysis

Corrosion initiation. Corrosion initiation was monitored by HCP measurement. A typical measurement of it is shown in Figure 3. The initiation of corrosion was determined by visual inspection of reinforcement bars after breaking the specimens. From both the measurement of HCP and visual inspection it can be concluded that the corrosion in Everdure Caltite modified concrete did not start until after 8 months exposure in the chamber. It is most likely that the corrosion started in the specimens at about the 14th month of exposure to saltwater spray.

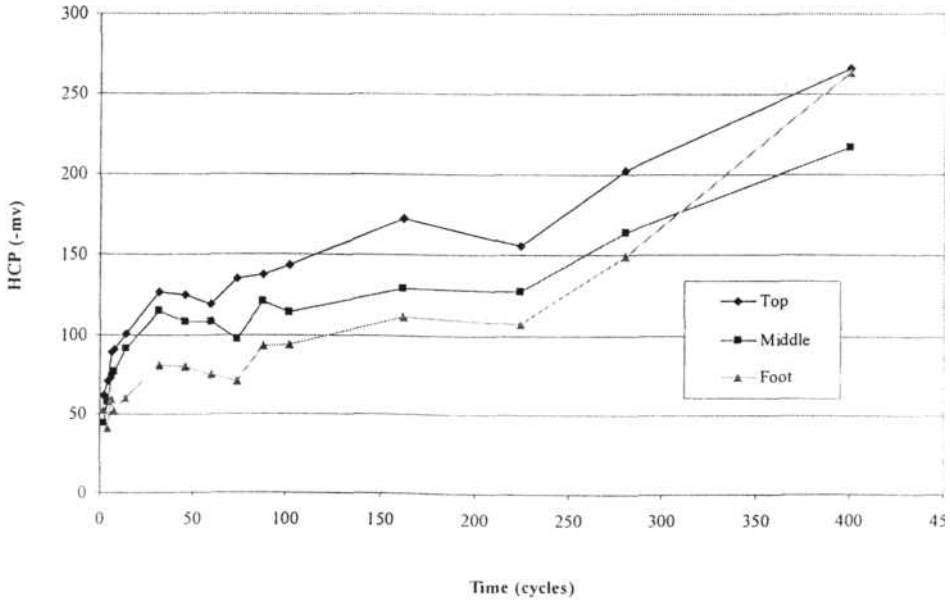
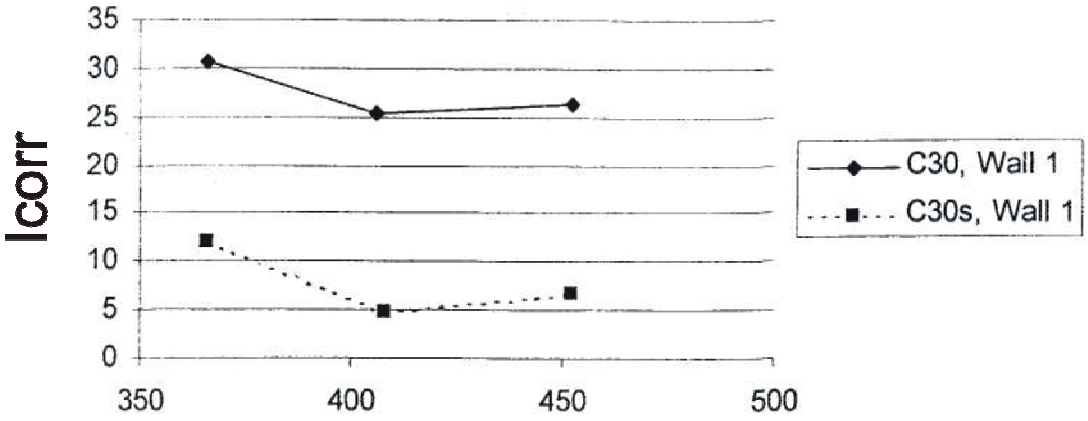


Figure 3 Half cell potential (HCP) vs time

As a comparison, the corrosion started in the specimens with ordinary Portland concrete in about 3-5 days of exposure to saltwater spray.

Corrosion propagation. Corrosion propagation was monitored by the measurement of LPR which was then converted to corrosion current density, denoted as i_{corr}, a typical measurement of which is shown in Figure 4.



Time (cycles) Figure 4 Corrosion current density i_{corr} vs time

A comparison is also shown in the figure which clearly indicates that corrosion progresses about 3 times as slowly as that in ordinary Portland concrete.

Area reduction. The cross-sectional area reduction of reinforcement bars is the most accurate measurement of corrosion effect on metal loss of reinforcement bars. Although impossible in the field it can be done in the laboratory after the loading test. The results are shown in Table 3.

Table 3 Area reduction of corroded bars

Time	Beginning	8 month	16 month
Actual diameter (mm)	10	9.97	9.89
Reduction in %	-	0.3	1.1

A comparison of area reduction of reinforcement bars in concrete modified with Everdure Caltite admixture with that of ordinary Portland concrete is shown in Table 4. As can be seen the Everdure Caltite admixture significantly mitigates the corrosion propagation.

Table 4 Comparison of area reduction (reduced in %)

Time	Beginning	8 month	16 month
With Caltite	-	0.3	1.1
Ordinary concrete	-	4.8	17.57

Load carrying capacity. The most accurate way to determine the residual capacity of a structure is by destructive loading test at the time required. This was carried out and the results are shown in Table 5.

Table 5 Load carrying capacity

Time	Beginning	8 month	16 month
Ultimate load (kN)	21.25	20.93	20.81
Reduction in %	-	1.5	2.1

A comparison of load carrying capacity of concrete walls modified with Everdure Caltite admixture with that of ordinary Portland concrete is shown in Table 6. As can be seen the Everdure Caltite admixture can significantly reduce the deterioration rate of the structure, in particular, in later stage of the service.

Table 6 Comparison of load carrying capacity (reduced in %)

Time	Beginning	8 month	16 month
With Caltite	-	1.5	2.1
Ordinary concrete	-	1.6	8.2
Percentage improved	-	6.7	290

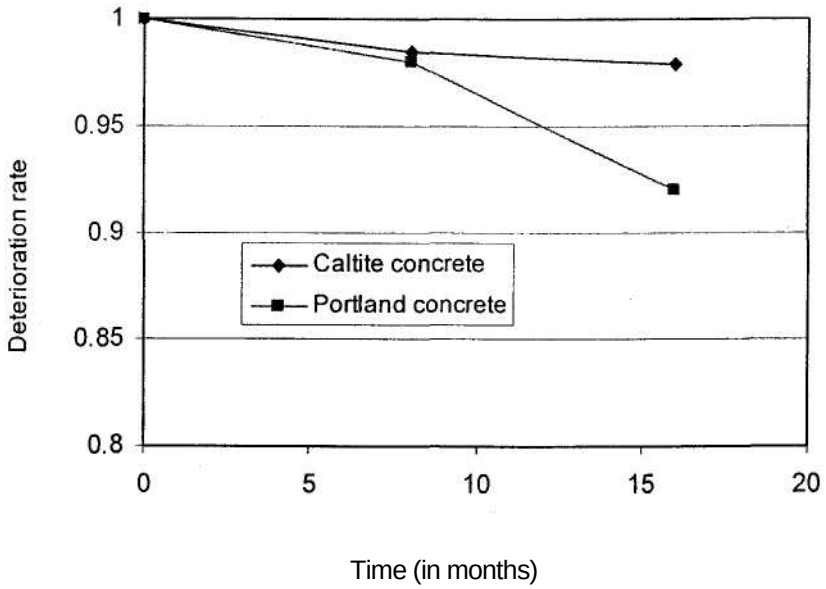


Figure 5 Comparison of deterioration of load carrying capacity for concrete structures with different concrete

Test time vs actual time. It is acknowledged that acceleration of the corrosion process by any means is not free of controversy. This is an issue which needs considerable research. The test programme has however been carefully considered in its design to ensure the validity of the results produced. A method of time transformation was developed to calibrate the "accelerated" test time to the actual time. Details of this method has been published by Li in American Concrete Institute materials journal. In this report a factor of 40 is used to transform the testing time to actual time. Therefore 8 months of testing time are about 26 years of actual time and 16 months are 52 years.

Conclusion

The following conclusions can be drawn from the analysis of experimental results:

- Concrete structures with Everdure Caltite admixture out-perform those with ordinary Portland cement concrete by all available measures.
- Corrosion does not initiate in concrete structures with Everdure Caltite admixture until after about 26 years.
- Corrosion in concrete structures with Everdure Caltite admixture only reduces the load carrying capacity of the structures by 2% in about 50 years.

The laboratory test carried out clearly indicate that Everdure Caltite will greatly increase the service life of concrete structures in marine and other areas which are subject to reinforcement corrosion due to the presence of chlorides. However, due to the limited number of tests undertaken, we recommend additional research be carried out to further substantiate these results-

References

ASTM C876, (1991), "Standard Test Method for Half-Cell Potentials of Uncoated Reinforcing Steel in Concrete", *ASTM,* Philadelphia, 425 - 430.

British Standards BS 8110, (1997), *Structural Use of Concrete - Code of Practice for Design and Construction,* BSI, London.

Li, C.Q. (2000), "Corrosion Initiation of Reinforcing Steel in Concrete under Natural Salt Spray and Service Loading - Results and Analysis", *ACI Materials Journal,* 97(6), 690 - 697.

Li, C.Q., (2001), "Initiation of Chloride Induced Reinforcement Corrosion in Concrete Structural Members - Experimentation", *ACI Structural Journal,* 98, (4), 501-510.

Li, C.Q., (2003), "Life Cycle Modelling of Corrosion Affected Concrete Structures - Propagation", *Journal of Structural Engineering, ASCE,* **129,** (6), 753 - 761.