“Impermeabilizzazione di tutte le strutture interrate del Terminal 3”:
Aereoporto Changi, SINGAPORE (7 livelli, di cui 3 interrati, 28 gates e 1.800 posti auto) per un totale di 150.000 mcubi di cls trattati.

Visione generale del cantiere

Mix design del calcestruzzo

Project: Pile Foundation & Basement
Construction for Terminal 3
Singapore Changi Airport

Contractor: Sato Kogyo., Ltd
8 March 2001
Ref: RE/SK/PU/40P/01

Concrete Grade 40 Pump

1	Specification 1.1 Specific Characteristic Strength 1.2 Designed Standard Deviation 1.3 Design Margin 1.4 Target Mean Strength 1.5 Free Water/Cement Ratio 1.6 Type of Concrete 1.7 Concrete slump	 40N/mm^2 at 28 days in accordance with BS 5328 4.6 N/mm^2 7.5 N/mm^2 47.5 N/mm^2 0.46 Pump Concrete 100±25mm
2	Cement 2.1 Cement Type 2.2 Cement Content	 Ordinary Portland Cement 398kg/m^3
3	Aggregates 3.1 Aggregate Type Coarse Fine 3.2 Relative Density of Aggregates 3.3 Normal Aggregate Size 3.4 Grading of Fine Aggregate 3.5 Coarse Aggregate Content: SSD 3.6 Fine Aggregate Content: SSD	 Crushed Granite Natural Sand/ Manufactured Sand 2.60-2.65 20mm BS 882 Table 5 1000 Kg/m^3 695 Kg/m^3
4	Water 4.1 Free Water Content	 185 Kg/m^3
5	Admixtures 5.1 Admixture Type 1 Dosage 5.2 Admixture Type 2 Dosage	 Penetron (mix design) Admixture 0.8 kg per 100 kg of cement Daratard 88. Water reducing, plasticizing and set retarding 550 ml per 100kg cement
6	Summary (Batch weighs (SSD) Per Cubic Metre of Concrete)	 Kg/m^3

Grade	Slump	Cement	Coarse Agg	Fine Agg	Water	Admix Penetron	A/C	W/C	Density
40	100±25mm	398	1000	695	185	3.18	4.26	0.46	2281.18

Controllo delle fessurazioni, efflorescenze e percolazioni ormai asciutte (ampiezza delle fessurazioni, natura e crescita dei cristalli nelle carote prelevate sulle pareti del diaframma al Changi Airport Terminal 3)

SETSCO

SETSCO SERVICES PTE LTD

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Our Ref: A6127/CHF **Date: 25/10/02**

TEST REPORT

(This Report is issued subject to the terms & conditions set out below)

MICROSCOPIC ANALYSIS ON THE CONCRETE CORES FROM RETAINING WALL AT CHANGI AIRPORT TERMINAL 3

Prepared for:
REVERTON ENGINEERING (S) PTE LTD
605A MacPherson Road #06-02
Citimac Industrial Complex
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Attn: Mr. Gary Loh

Report prepared by:
Chen Hong Fang
Senior Engineer
Construction Technology Division

Report reviewed and approved by:
Wong Chung Wan
Divisional Director
Construction Technology Department

CPG
CONSULTANTS

Your Ref :
Our Ref : CPGCorp/ADD/S1001.3.2
Date : 21 Dec 2004

AIRPORT DEVELOPMENT DIVISION
1800 UPPER CHANGI ROAD NORTH
SINGAPORE 507695
Tel: 65437304 Fax: 65420406
Email: kueh.lip.kuang@cpgcorp.com.sg

To whom it may concern

We herewith confirm that Penetron Admix and other components of Penetron concrete waterproofing system have been used exclusively to waterproof and protect the entire substructure of Terminal 3 at Changi Airport.

This project was built completely on reclaimed land and as such presented a formidable challenge for any waterproofing company.

Now that the defect liability period of 18 months has expired without report of any significant leakage, we are happy to state that we are very satisfied with both the performance of Penetron products and the responsible and co-operative work attitude of the local Penetron team, headed by Mr Gary Loh form Reverton Engineering.

I wish them all the best in their future endeavours.

Yours faithfully,

Kueh Lip Kuang
Vice President (Civil & Structural)
Airport Development Division
CPG Consultants Pte Ltd

1. INTRODUCTION

Cracking and seepage of water on the retaining wall at Changi Airport Terminal 3 was reported by Reverton Engineering (s) Pte Ltd (herein refers to as the Client). SETSCO has been engaged by the Client to carry out laboratory analysis to determine the crack width and crystal growth in the crack on the concrete cores extracted from the said structure.

The proposed basement was constructed with three sides of wall, labelled as wall 1-3 in this report (refer to figure 1 in Appendix). Thickness of the wall was about 600mm. PENETRON waterproofing admixture was said to be used in the concrete. Water leakage was found along the crack line and tie pin after backfill. However, the water leakage has been stopped on wall 1, which was cast somewhere in 2001. On wall 3, water leakage from the tie pin or crack was noticed during extraction of cores on 05/10/2002. Sign of efflorescence was found on all three sides of the walls. Most of the efflorescence emanated from the tie pins, but cracks with some sign of efflorescence were also noted at some areas (Refer to the photographs in Appendix).

A total of three core samples were extracted from wall 1. Samples S1 and S3 were extracted from crack area while sample S2 was taken at the tie pin. During extraction, the cores were drilled to a depth of 400mm but due to the presence of reinforcement, the length of the core S3 removed was only 240mm.

2. MICORSCOPIC ANALYSIS

The microscopic analysis was performed on a ground section using a stereo microscope and metallurgical microscope and on a thin section with a polarising and fluorescent microscope (PFM) under transmitted and reflected light. For preparation of the ground section, a small block of the sample was cut and ground to attain a smooth finish. For preparation of a thin section, a small concrete block was sawn from the core sample, glued to an object glass and impregnated with an epoxy resin containing a fluorescent dye. After hardening of the epoxy, a thin section with a surface area of approximately 33 x 63 mm and a thickness of 20-30um was prepared for PFM analysis.

Under transmitted light, the various components (type of cement and aggregates), air voids content, compaction pores and damage phenomena in the samples were identified. Under reflected light, the fluorescent microscopy made it possible to study the homogeneity of the mix and the cement paste, capillary porosity, microcracks and other defects in the samples. Scanning Electron Microscope (SEM) and Energy Dispersive X-ray (EDX) Analysis technique was also applied for semi-quantitatively analysis of the element composition of the crystals present in the crack and topography of the crystals.

In summary, SEM utilises a beam of electrons in a vacuum environment to form an image of the surface topography of a sample. Such magnified images are characterised by a high level of resolution and good depth of view. The characteristic X-ray emitted from the sample surface upon being irradiated with the electrons are then analysed using an EDX accessory/detector that is coupled to the SEM, allowing evaluation of the % elemental content at the irradiated areas/spots on the sample

3. RESULTS

i) Visual examination

The length of the cores varied from 240mm to 310mm. Crack perpendicular to the surface was noted in samples S1 and S3. The width of the crack ranged from 0.04mm to 0.3mm. The paste matrix appeared light grey in colour while the paste matrix was noted to be generally light grey.

Thin sections were prepared at the top of sample S2 and end of sample S3 for further microscopic analysis. Stereo microscope and SEM-EDX analysis were performed on sample S3 to determine the presence of the crystals in the crack and their elemental composition.

ii) Microscopic analysis

Under stereo microscope, a lot of coarse-grained elongated crystals were seen lining the crack. Thin section of sample S3 showed that coarse-grained elongated crystals and fine-grained needle-like crystals in the crack. All these crystals showed low birefringence under crossed polarised microscope.

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Further scanning electron microscope and energy dispersive x-ray analysis was performed on the crystals present in the crack. The coarse-grained elongated crystal (BEI image in Appendix) contained mainly *Calcium* (Ca), *Oxygen* (O) and *Silicon* (Si). The fine-grained needle-like crystal was predominantly made up of *Calcium* (Ca), *Silicon* (Si), *Oxygen* (O), *Sulfur* (S), *Aluminium* (Al), which was probably ettringite ($C_6A\underline{S}_3H_{32}$).

Well-formed CaCO3 crystals were present as laminated texture on the surface of sample S2.

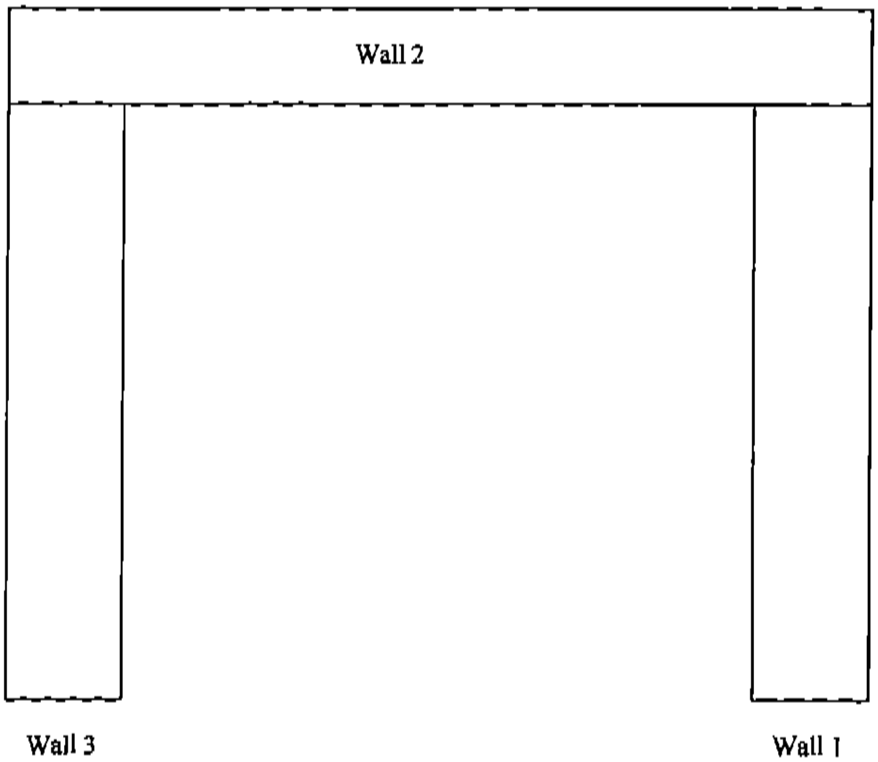


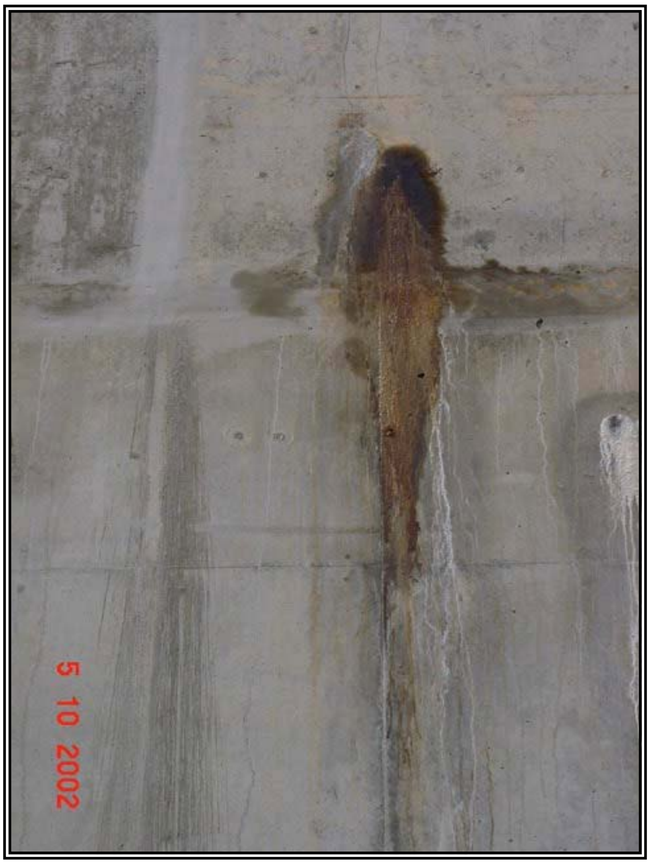
Figure 1: The layout of the retaining wall

Casting date of extracted cores

Sample reference	*Date of cast*
S1	19/12/2001
S2	19/12/2001
S3	06/08/2001

Sign of efflorescence with water marks were noted on wall 3.

Close view of the sign of efflorescence accompanied with water marks were noted on wall 3.



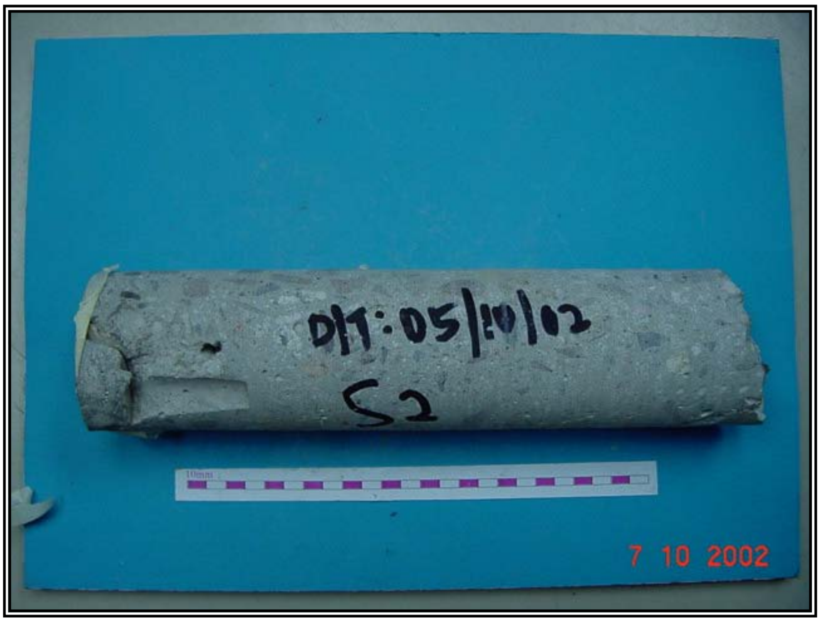
Brownish staining with water leakage was on wall 3.

The location of sample S1 extracted at the cracked area on wall 1.

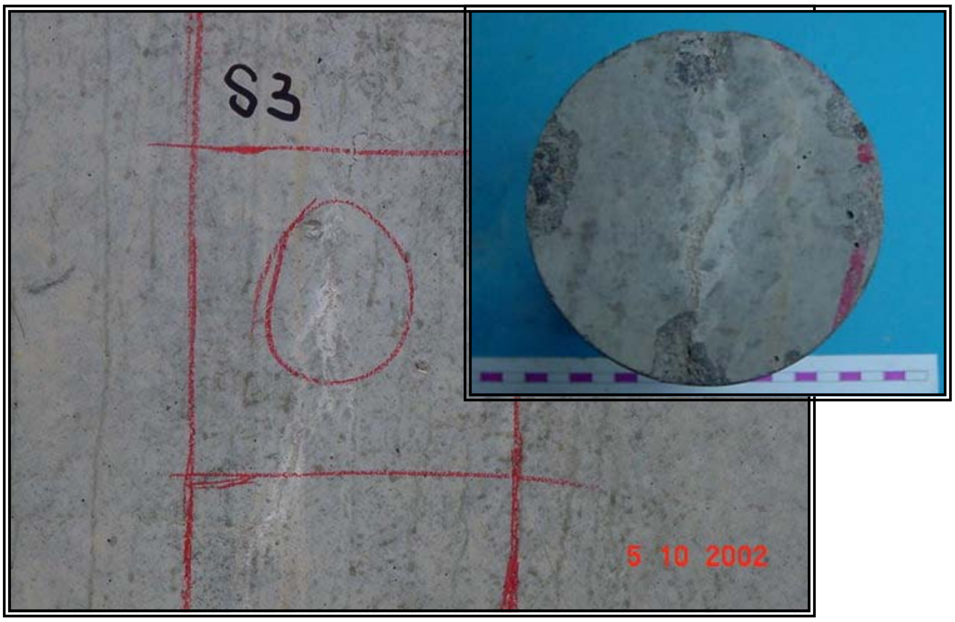
A 75mm diameter core containing a crack at wall 1 was extracted for laboratory analysis.

A crack perpendicular to the exposed surface was seen in core S1.

Core S2 was extracted at the tie pin on wall 1.

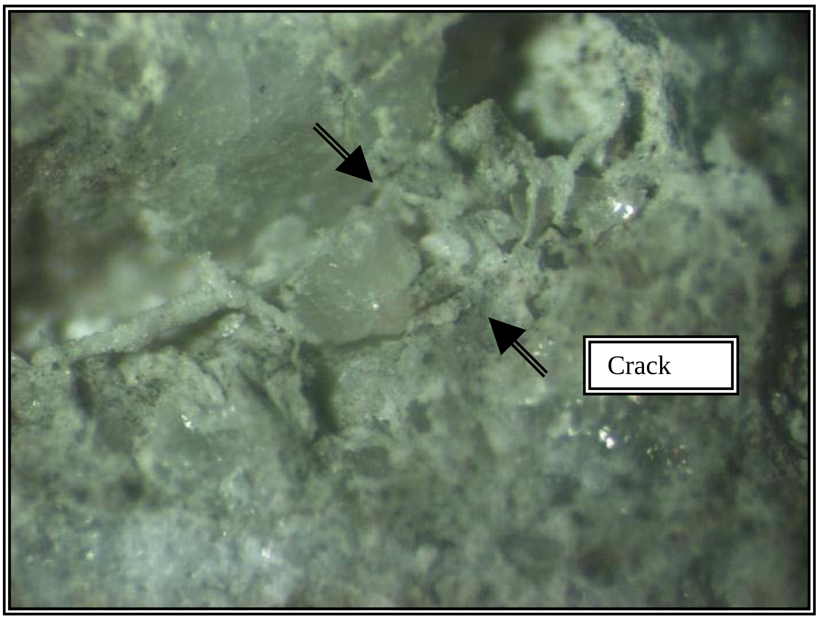


Relative thick whitish substance was on the surface of core S2.

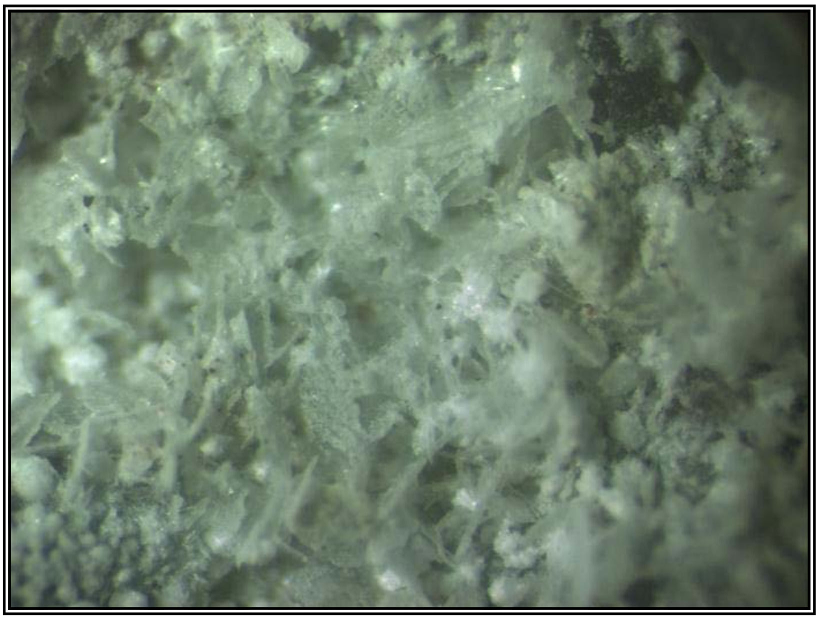


Sign of efflorescence was found along the crack line where core S3 was taken on wall 1.

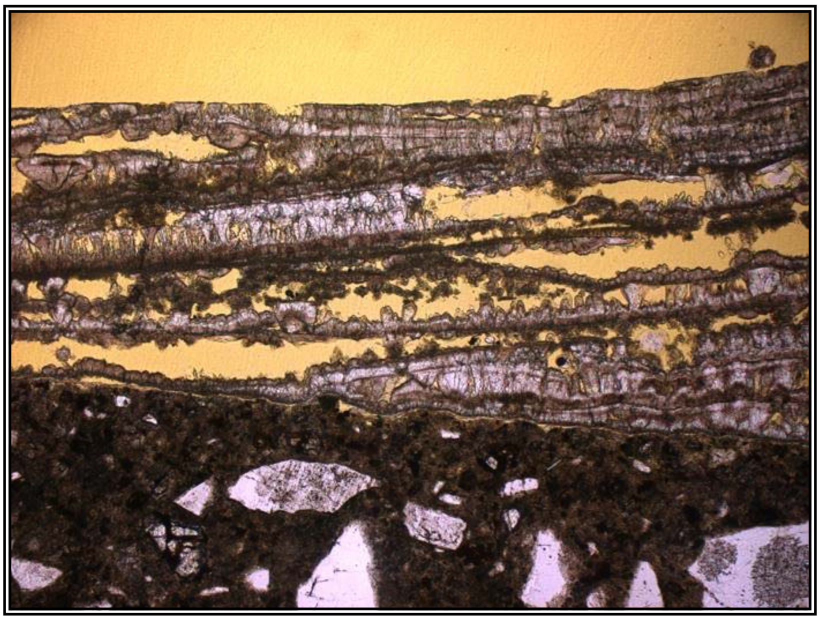
A crack perpendicular to the exposed surface was seen in core S3.



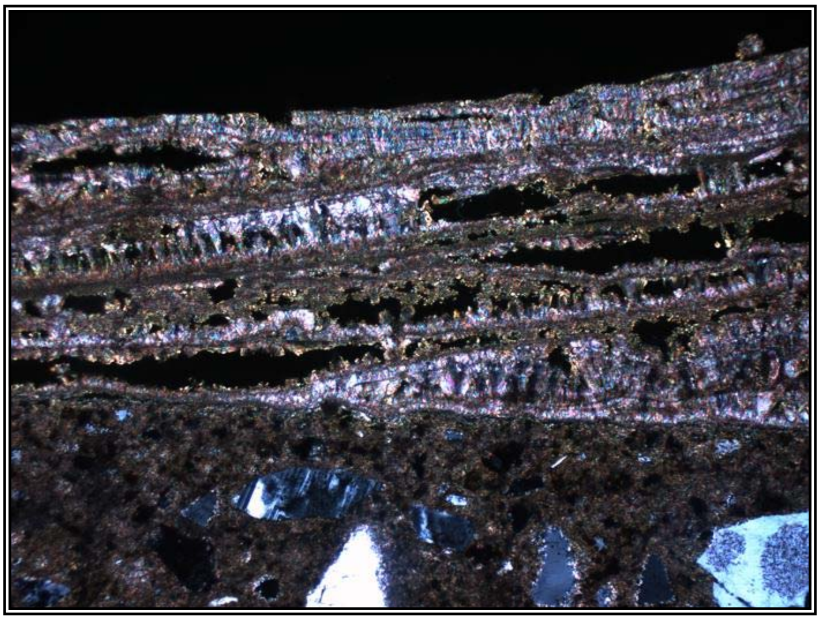
Sample S3: Some crystals grew in the crack.



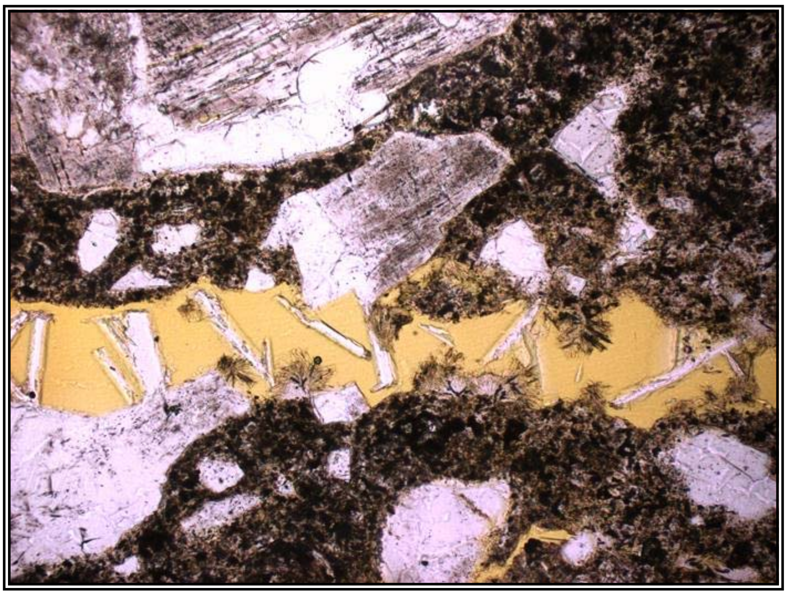
Sample S3: Abundant coarse-grained crystals in the crack.



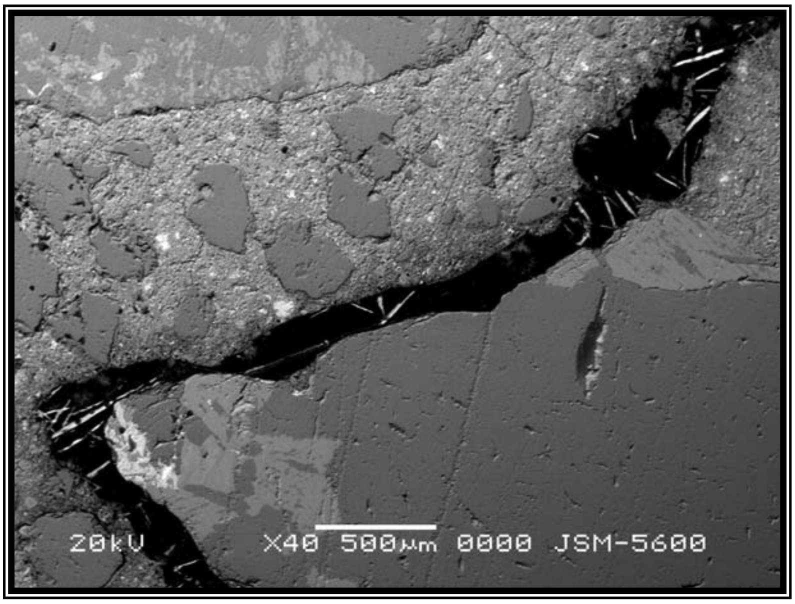
Sample S2: Laminated CaCO3 crystals on the surface of the concrete. The width of the field is 3.88mm under plane light.



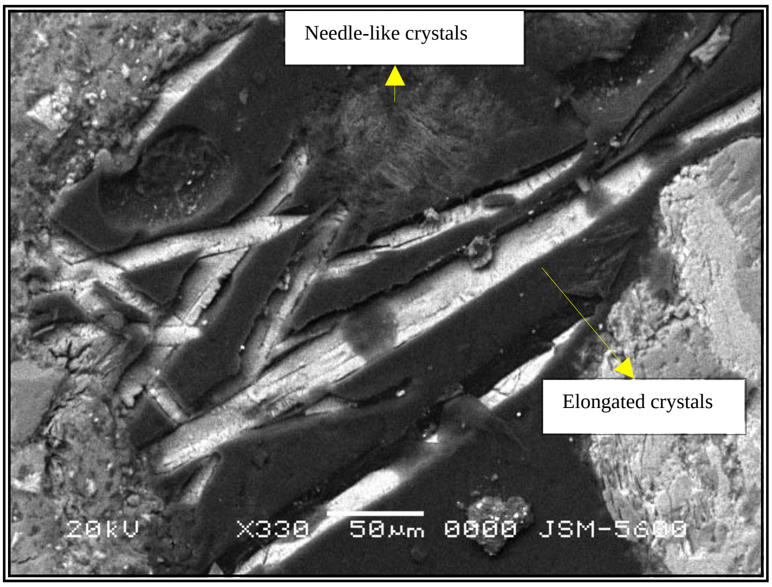
Sample S2: Laminated CaCO3 crystals on the surface of the concrete. The width of the field is 3.88mm under crossed polarised light.



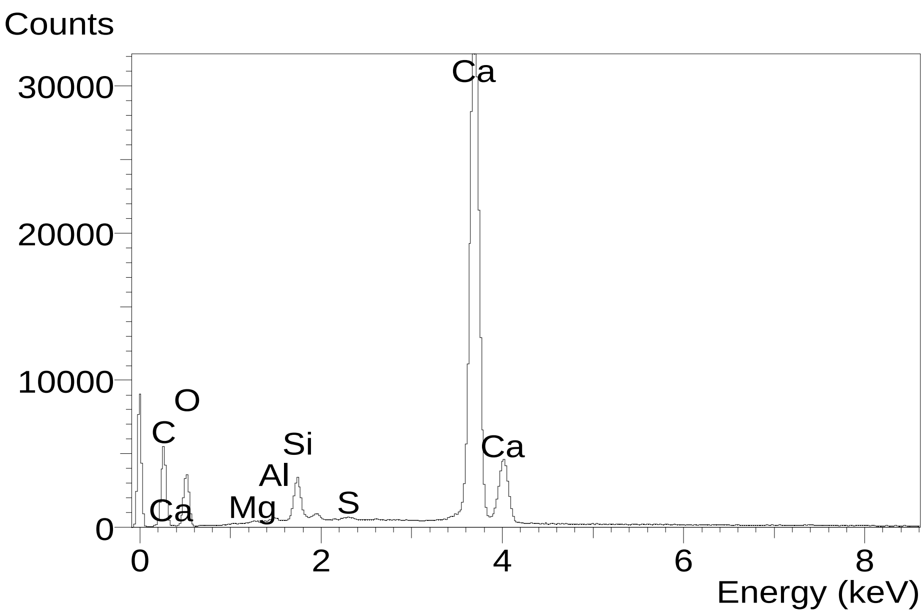
Sample S3: Coarse-grained elongated crystals and fine-grained needle-like crystals were lining the crack. The width of the field is 3.88mm under plain light.



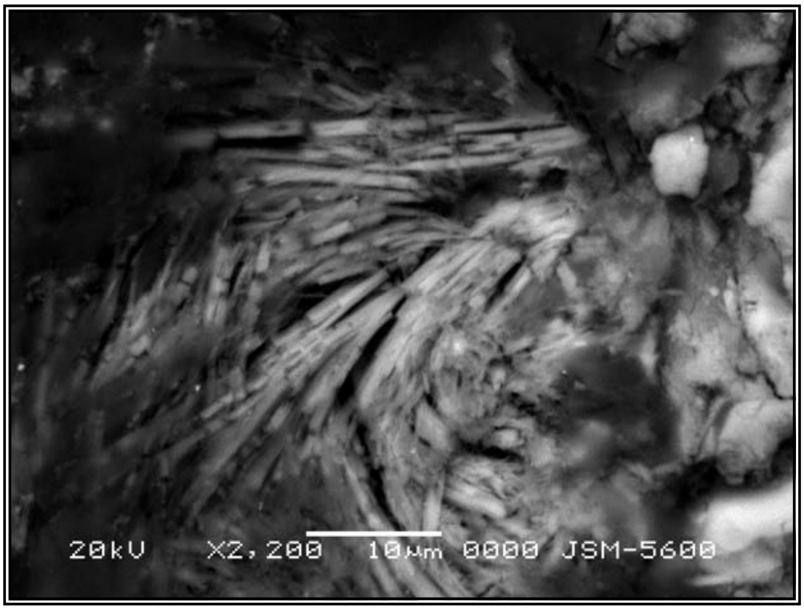
Sample S3: Backscattered electron image (BEI) showed some crystals were in the crack.



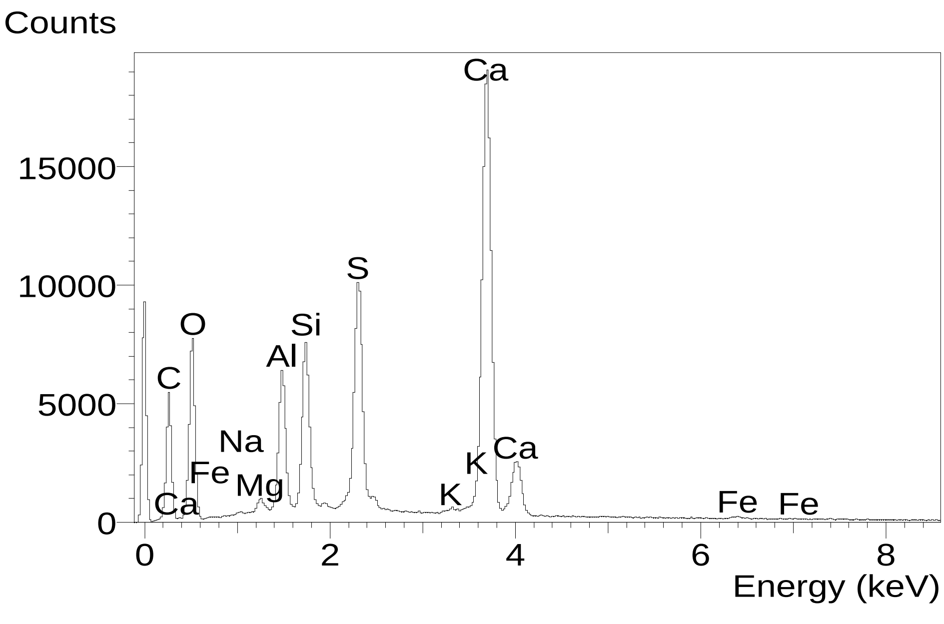
Sample S3: Backscattered electron image (BEI) showed elongated crystals and fine needle-like crystals in the crack.



EDX spectrum of elongated crystals in the crack.



Sample S3: High magnified view of needle-like crystals in the crack.



EDX spectrum of needle-like crystals in the crack.

Sample S3: Secondary electron image (SEI) showed coarse-grained flaky crystals in the crack.

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Our ref: A3747/WCW Date: 31/05/2001

TEST REPORT

(This Report is issued subject to the terms & conditions set out below)

Report on
Performance Assessment of Penetron Waterproofing Admixture

Prepared for
Reverton Engineering (S) Pte Ltd
605A, MacPherson Road, #06-02
Citimac Industrial Complex
Singapore 368240
Attn: Mr. Gary Loh

Assessed by:

Wong Chung Wan (Divisional Manager)

Karen Tay Yen Ping (Engineer)

Chen Hong Fang (Executive Engineer)

1. Introduction

Reverton Engineering (S) Pte Ltd (Reverton) has engaged SETSCO to carry out an independent assessment on the performance of Penetron Waterproofing Admixture when used in concrete for the Pile Foundation and Basement Construction for Changi Airport Terminal 3 project.

The primary objective of the assessment is to determine the efficacy of the admixture to reduce the ingress of water through the concrete and thus making the concrete 'water tight'. SETSCO has earlier been commissioned to carry out tests on concrete cubes cast during trial mixes for:

i) resistance to water penetration in accordance with DIN 1048
ii) water permeability based on Darcy's formula using the HDB's method
iii) microscopic examination based on ASTM C856 with scanning electron microscopy-energy dispersive x-ray analysis (SEM-EDX).

The assessment is carried out by reviewing data of tests done by SETSCO and others as furnished by Reverton and technical literature submitted on the waterproofing admixture used.

2. Background

Trial mixes of concrete have been prepared by PanUnited Concrete for Concrete grade 40 pump mix. The design mix is given in the Appendix. The mix design for concrete treated with Penetron Admixture was said to be similar to the control mix except that the latter did not have the Penetron Admixture. Cubes were cast for determination of compressive strengths, water penetration test and water permeability test. Data was given by Reverton on the following trial mixes:

i) 28 November 2000 on G40 control concrete
ii) 18 March 2001 on G40 concrete with Penetron Admixture
iii) 11 April 2001 on G40 concrete with Penetron Admixture
iv) 19 April 2001 on G40 control concrete

Cubes cast during the trial mix on 18 March were submitted for water permeability test whilst the cubes prepared for the trial mix on 11 April 2001 was subjected to water penetration test. The cubes from the control concrete mix made on 19 April 2001 were tested for water penetration test. The compressive strength test on the cubes were conducted by PWD Consultants and the results were furnished by Reverton.

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3. Summary of test results

A summary of the test results is as follows:

Properties determined	Age of concrete (days)	Treated concrete	Control concrete
Water penetration (DIN 1045), mm	7	15.6	29.2 [1]
	21	11.2	29.4 [2]
	28	9.6	16.0 [3]
Coefficient of permeability, m/s	28	7.30×10^{-13}	N.A.
	56	5.35×10^{-13}	N.A.
Average compressive strength N/mm2	7	44.0	41.5
	28	47.5	46.0

Note:
[1]: Age of control concrete at time of test was 9 days
[2]: Age of control concrete at time of test was 23 days
[3]: Age of control concrete at time of test was 29 days
N.A.: Not available as no test was conducted on the control concrete

4. Literature review

4.1 Water proofing admixtures

Water penetrates concrete under conditions of pressure or by absorption. In the former, water under pressure and in contact with one surface of the concrete is forced through channels which interconnect the two faces of concrete. In the latter, the passage of moisture through concrete occurs merely by capillary action. An integral waterproofing admixture is a powder, liquid of suspension which when mixed with fresh concrete results in:

i) a reduction in the permeability of cured concrete and
ii) imparts a water repelling or hydrophobic property to hardened concrete

Admixture that reduce the permeability of concrete (waterproofing) are effective in reducing the transport of moisture under pressure whereas materials that impart water repellency (dampproofing) may reduce moisture migration by capillary action. Admixtures for the latter include chemically finely divided solids and conventional water reducing admixtures.

4.2 Penetron Crystallizing waterproofing admixture

Penetron Admixture, according to the brochure is a crystallizing waterproofing admixture. Crystallizing water proofing admixtures generally comprise of fine chemically reactive powders that reduce the permeability of the concrete by reacting with the free lime and calcium hydroxide in the concrete to produce additional cementitious material, primarily, calcium silicate hydrates and calcium aluminate silicate hydrates. The product of this reaction is a non-soluble crystalline dendritic structure in bleed water tracts, capillary tracts and shrinkage cracks in concrete. This chemical reaction provides a watertight/waterproof concrete.

4.3 Mix design

The grade of the treated concrete is G40 pump mix with a cement content of 398 kg/m3. Daratard 88 plasticising and set retarding admixture was also added. The cement designed for was Ordinary Portland cement and the free water cement ratio 0.46. The design mix for the control concrete was said to be similar to the treated concrete except for the absence of Penetron Admixture. Such mix design would have rendered the concrete, including the control mix, suitable for exposure to a very severe condition.

5. Performance assessment

5.1 Compressive strength

From the data furnished, the compressive strength of concrete cubes made and tested at 28 days range from 44.5 to 50.5 N/mm2 with an average of 47.5.0 N/mm2. The 7 days strength varied from 41.5 to 46.0 N/mm2 averaging at 44.0N/mm2. In some cases, there were little gain in strength from 7 to 28 days and in others, the gain was as much as 14%. The average 7 and 28 days compressive strength of the control concrete was 41.5 and 46.0 N/mm2 respectively. The figures show that the admixture did not have any adverse effect on the strength of the concrete.

5.2 Resistance to water penetration

Despite the same water cement ratio and cement content, which produced primarily similar compressive strength, the depths of water penetration for the concrete with Penetron Admixture at various ages are significantly lower than the control concrete. At the age of 28 days for example, the admixture has reduced the water penetration of concrete by about 40% with greater improvement at earlier ages. The total average penetration for the control concrete at 28 days was 16.0mm whilst that treated with Penetron Admixture was only 9.6mm. According to DIN 1045, the maximum allowable depths for water penetration for concrete specified under 'impermeable to water' is 50 mm when tested in accordance with DIN 1048. For concrete required to resist seawater and strong chemical attack, the maximum allowable penetration is 30mm. It would appear that both the control and treated concrete satisfy both the requirements given in DIN 1045 with the treated concrete performing significantly better.

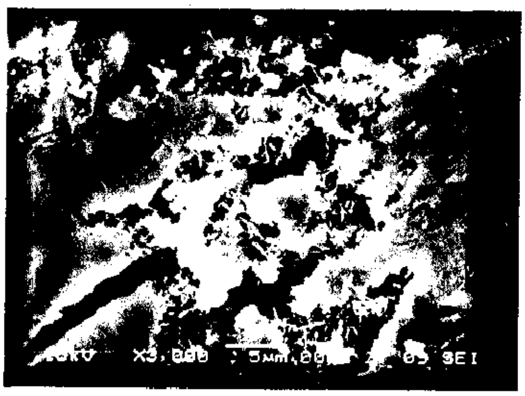
The Penetron Admixture has evidently reduced the porosity and permeability even of a water tight control and laboratory prepared concrete without reducing the water cement ratio. The improvement is expected to be more pronounced in concrete of lower quality and concrete cast in-situ. This could easily be confirmed by testing of in-situ concrete using cores.

5.3 Water permeability

The coefficient of water permeability of the treated concrete (with Penetron Admixture) is in the range of 10^{-13} m/s. According to guides given in the Concrete Society Technical Report No. 31, such value is typically a concrete with low permeability.

5.4 Microscopic examination

The SEM-EDX analysis conducted on the treated concrete showed the presence of dendritic crystals (see fig 1). These crystals are found in pores such as capillary tracts, shrinkage cracks and bleed water tracts that allow crystallization of the additional cementitious material. See photomicrographs in the appendix. This clearly shows the crystallization effect of Penetron Admixture which reduces and seals the pores in the concrete. It is believed that with further curing or under continued damp condition, further sealing of the pores is expected making the concrete water tight.



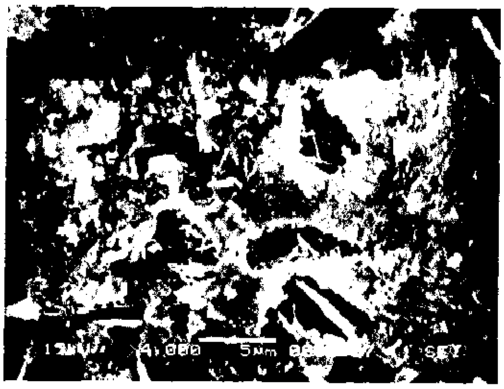


Fig 1: Images of needle-like crystals in the concrete treated with Penetron admixture.

5.5 Durability

The durability of the concrete must be assessed with respect to the exposure condition of the structure in which the concrete is used, the design life or criteria, use of the structure and construction. Based on the analysis of ground water, the pH of the water is near neutral (pH of 6.4) and the sulphate content as SO_3 is low (~0.1 g/litre). The chloride content in the groundwater however, was quite high (~6700 mg/l). The external exposure environment is thus classified as severe. Concrete with low permeability with a maximum free w/c ratio of 0.45 is recommended.

As for the use of the structure, the requirement for a car park for instance could very well differ from say, a plant room or office. Slight dampness or water seepage could be tolerated in a carpark but not in the plant room. The acceptable risk of moisture penetration associated with each type of structure must also be evaluated in view of the existing and possible future ground conditions.

Design life and criteria should be addressed by the designer. Consideration should also be given to construction method used to minimize cracking arising from shrinkage, thermal and restraints. Protection against water penetration relies on the design and construction of high quality concrete, with cracking controlled to prevent penetration of moisture to an unacceptable degree.

Notwithstanding these factors, the mix design of the treated concrete alone indicate good resistance against chemical attack, leaching and water penetration provided that the concrete has been well placed and compacted.

6. Conclusion

The admixture used has no adverse effect on the strength and strength development of the concrete.

Generally, the concrete prepared during the trial mix with Penetron Admixture showed high resistance to water penetration. Marked improvement could be seen in the treated concrete despite the high quality control concrete. Based on guidelines given in DIN 1045, the treated concrete complies with the requirements for water resistant/waterproof concrete.

The coefficient of permeability of the treated concrete fell into typical values for low permeability based on guides given by the Concrete Society. No corresponding value on the control concrete was available.

The dendritic crystals arising from the reaction of the admixture with the hydrates of cement were seen in the pores of the treated concrete. The crystals forming in the pores reduce the porosity of the concrete by sealing the pores. The will effectively enhance the durability of the concrete by preventing ingress of water and chemicals that destroy the matrix of the cement hydrate.

Assessment of durability of the concrete need to take into consideration many other factors such as type of structure, exposure condition, design criteria and construction. However, due to its crystallization effect which reduces its porosity and permeability and seals fine cracks, such concrete is expected to give good resistance to water ingress and chemical attack over a normal concrete. This should not be taken as a replacement or a solution for poor design, detailing and workmanship. References should be make to BS 8102, BS 8007 and CIRIA Report 139 for further guidance.