CAUSES AND MECHANISMS OF DISTRESS IN CONCRETE SEAWALL BLOCKS AT TSANG TSUI ASH LAGOONS

GEO REPORT No. 209

R.J. Sewell, K.C. Ho, C.L. Leung & K.Y. Leung

GEOTECHNICAL ENGINEERING OFFICE

CIVIL ENGINEERING AND DEVELOPMENT DEPARTMENT

THE GOVERNMENT OF THE HONG KONG SPECIAL ADMINISTRATIVE REGION

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PREFACE

In keeping with our policy of releasing information which may be of general interest to the geotechnical profession and the public, we make available selected internal reports in a series of publications termed the GEO Report series. The GEO Reports can be downloaded from the website of the Civil Engineering and Development Department (http://www.cedd.gov.hk) on the Internet. Printed copies are also available for some GEO Reports. For printed copies, a charge is made to cover the cost of printing.

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R.K.S. Chan
Head, Geotechnical Engineering Office
August 2007

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FOREWORD

This report describes the results of a detailed study of distress in concrete seawall blocks at Tsang Tsui Ash Lagoon, Deep Bay, Hong Kong. The work was carried out by the Hong Kong Geological Survey Section of Planning Division, with assistance from LPM Division 2. The seawall blocks belonged to a set of field trials conducted by China Light and Power Company Limited (CLP) on the use of pulverized fuel ash (PFA) for the production of concrete. The study comprised two main parts: a petrographic examination of distressed seawall blocks to investigate potential alkali reactive materials, and a related study which examined the development of cracking and extent of deformation of the distressed seawall blocks.

Dr R.J. Sewell, the senior author of the report, managed the concrete study, in which he was supported principally by Mr K.C. Ho on the supervision of ground investigation and petrographic examination of the seawall blocks, and Ms C.L Leung and Ms K.Y. Leung who carried out the distress measurements of the seawall blocks. Dr S.D.G. Campbell (formerly of GEO) provided guidance during the initial stages of the study, and Mr Y.C. Chan reviewed this report. We are grateful to Mr Stan Cheesman, and colleagues at CLP, for assistance with identification of distressed blocks and access to the study site, respectively. Technical support was provided by staff of Geological Survey Section, Geotechnical Projects Division, and Survey Division.

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ABSTRACT

Six concrete seawall blocks at Tsang Tsui Ash Lagoon, Deep Bay, showing visible signs of distress, were the subject of a detailed petrographic examination and deformation survey. The seawall blocks belonged to a set of field trials on the use of pulverized fuel ash (PFA) for the production of concrete and all were suspected of having undergone alkali-aggregate reaction (AAR). Predominantly granite aggregate was used for the concrete production. The distressed seawall blocks were made of both sulphate-resisting cement (SRC) and ordinary Portland cement (OPC), and were known not to contain PFA. An additional seawall block showing no obvious signs of deterioration, and containing 25% PFA, was analysed for control purposes.

Casting and curing records have revealed that seawater was used for curing of all monitored seawall blocks. The ambient daytime temperatures at the time of casting varied from 24.6ºC to 29.0ºC and internal temperatures of the concrete during curing ranged between 74.1ºC and 90.9ºC.

Despite visible signs of AAR-type deterioration of the concrete, such as map pattern cracking, discolouration, and volumetric expansion, petrographic examination of the distressed seawall blocks has revealed the presence of relatively small amounts of alkali-silica gel (a product of AAR). In contrast, there is an abundance of ettringite infilling cracks in the cement paste, ring cracks around aggregates, and entrapped air voids within the concrete.

The alkali reactive material within granite aggregate appears to be microcrystalline to cryptocrystalline quartz within rare thin veins of tuffisite, and possibly granulated quartz associated with cataclasite within microfractures. These components make up less than 0.1% by volume of the aggregate. Ettringite has formed largely from secondary processes, and some crystal growth may have post-dated deposition of alkali-silica gel.

Two main styles of surface cracking can be distinguished in the distressed seawall blocks (a) map pattern cracking, and (b) longitudinal cracking. Map pattern cracking is typical of volumetric expansion of the cement paste reported for ASR-affected concrete, but here appears also to be associated with growth of secondary ettringite. The origin of longitudinal cracking is not clear and requires further investigation.

Preliminary measurements of deformation in the upper portions of the seawall blocks suggest that the least expansion is recorded by the control sample made of OPC and containing PFA. Seawall blocks made of SRC appear to be the next least expansive, followed by seawall blocks made of OPC which apparently show the greatest expansion.

Overall, the granite aggregate used in the production of the concrete seawall blocks at Tsang Tsui Ash Lagoons appears to be largely non-reactive with respect to AAR. General expansion of the cement paste causing serious distress in the seawall blocks is likely to be the result of a small proportion of AAR and considerable delayed ettringite formation (DEF). The use of PFA in the concrete appears to have greatly reduced the potential for deterioration.

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1. INTRODUCTION

1.1 Background

In 1988, China Light & Power Co. Ltd (CLP) initiated a comprehensive research programme to examine the use of pulverized fuel ash (PFA) for the production of concrete in all major applications in Hong Kong (CLP, 1990a). The research programme comprised field and laboratory testing of nearly 4,000 samples of various types of mix design and settings, and monitoring of performance over a period of 11 years. The aggregate used for concrete production was crushed granite from Lamma Quarry supplied by Lamma Rock Products Ltd.

The field testing was carried out during the construction of seawall blocks for CLP's ash lagoons at Tsang Tsui, Deep Bay (Figure 1, Plate 1). Among the various mix designs tested were nine seawall blocks containing 0% PFA. At Year 11, serious deterioration in the form of severe map pattern cracking and expansion was observed in these seawall blocks. Alkali-aggregate reaction (AAR) was suspected to be the main cause of the deterioration since an earlier report by Geomaterials Research Services Ltd. (1993) had concluded that some rocks from Lamma Quarry were potentially reactive.

A petrographic study carried out on several seawall blocks as part of the final report on PFA concrete studies (Geomaterials Research Services Limited in CLP, 2002) identified trace quantities of material resembling gel within cracks and voids of two seawall blocks. However, the presence of abundant fibrous material resembling ettringite within cracks and voids was also reported. The study concluded that while a small proportion of cracking could be related to AAR, some of the cracks in the distressed seawall blocks could also reflect general expansion of the cement paste due to secondary ettringite formation, and possibly delayed ettringite formation (DEF).

1.2 Description of the Project

As a result of the CLP's initial findings, a detailed petrographic examination and preliminary deformation survey were initiated in order to investigate the causes and mechanisms of distress in concrete seawall blocks at Tsang Tsui Ash Lagoons. The petrographic examination was carried out according to ASTM C 856 (1995) and the RILEM AAR1 method (RILEM, 2002) on concrete core samples recovered from selected seawall blocks. The preliminary deformation survey involved detailed *in situ* measurements of the style and degree of cracking and expansion in the upper portion of the distressed seawall blocks. The project was undertaken between December 2004 and June 2006.

1.3 Scope and Objectives

The scope of the project was limited to examining six concrete seawall blocks showing visible evidence for deterioration, such as map pattern cracking, discolouration of concrete to a pale brown colour, ring cracking around aggregates, and volumetric expansion relative to adjacent seawall blocks, as well as one seawall block showing no apparent deterioration. Each of the six distressed seawall blocks was known to contain 0% PFA, and included one seawall block (WW34) previously studied in detail by CLP. Two of the distressed seawall blocks (WW9A & WW9B) were made of sulphate-resisting cement (SRC) whereas the

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remaining four seawall blocks were made of ordinary Portland cement (OPC). The seawall block showing no apparent deterioration (WW28) was made of OPC and contained 25% PFA.

The principal objectives of the project included:

(a) to determine whether the primary cause of cracking and expansion in the affected seawall blocks was due to AAR or other deleterious processes,

(b) to determine whether the different mix designs had an influence on the distress of the affected seawall blocks, and

(c) to determine whether other environmental factors may have influenced the deterioration of the seawall blocks.

The general arrangement of seawall blocks investigated in this report is shown in Table 1. A general section and plan view of a typical seawall block, according to the design dimensions given by CLP (1990b), is illustrated in Figures 2 and 3 respectively.

2. MIX DESIGN, CASTING AND CURING CONDITIONS OF SEAWALL BLOCKS

Mix design, mix proportions, casting and curing records for the monitored seawall blocks are summarized in Tables 2 and 3.

The monitored seawall blocks were cast and cured between 13.10.88 and 8.11.88. Each seawall block required approximately three truck loads (nominal capacity 6 m^3) of concrete to complete casting. Except for WW9A and WW3, casting generally was completed within two hours. WW3 took 3 hours 20 minutes to cast, whereas WW9A took 5 hours 30 minutes to cast due to mechanical breakdown. Owing to the long casting period, serious "cold joint" characteristics developed in WW9A and therefore a substitute seawall block (WW9B) was cast. Curing generally commenced approximately 26 hours after casting and lasted approximately 48 hours. The exceptions to this were WW9B in which curing commenced approximately 6 hours after casting, and WW28 where curing lasted for 72 hours.

Ambient daytime temperatures at the time of casting varied from 24.6ºC to 29.0ºC and the temperatures of fresh concrete varied from 28.7ºC to 32.0ºC. Hessian soaked in seawater was used for all curing. Minor shrinkage cracks were noted in WW9A and WW28. Thermocouples were installed in all monitored seawall blocks except WW3. Internal temperatures in the concrete varied between 74.1ºC and 90.9ºC during early curing.

Identical concrete mixes were used for WW3 and WW5, and the only significant difference in casting and curing conditions was that WW3 (3 hours 20 minutes) took more than twice as long as WW5 (1 hour 40 minutes) to cast. Apart from length of time taken for casting, other differences in conditions for the two SRC seawall blocks (WW9A and WW9B) included (i) the use of a steel mould (WW9A) or timber mould (WW9B), (ii) the casting as an "infill" block (WW9A) or isolated block (WW9B), and (iii) the length of time taken for curing (28 hours 40 minutes for WW9A and 6 hours and 15 minutes for WW9B).

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The molecular ratio of SO_3/Al_2O_3 in the monitored seawall blocks varied between 0.43 (for SRC) and 0.55 (for OPC), whereas measured water/cement ratios varied between 0.47 (WW35) and 0.69 (WW34).

3. METHODOLOGY

3.1 Sampling of Concrete

Sampling was carried out using water flush drilling with single tube core barrels. Selection of corehole locations on the seawall blocks was based on careful observation of cracking, exudation, and discolouration of concrete surfaces. In general, the coreholes were located at or close to the triple junctions of major cracks in order to obtain the maximum information on the cause of cracking (Plate 2).

Corehole diameters (67 mm) were not less than three times the maximum size of coarse aggregate (20 mm) in accordance with ASTM C 856 (1995). Corehole depths ranged between 1260 mm and 2070 mm. Details of corehole samples recovered from the seawall blocks, including duplicate samples, are given in Table 4.

3.2 Specimen Selection and Thin Section/Polished Slab Preparation

The top 300 mm of each core was photographed with scale bar prior to cutting. Both vertical 10 mm thick 60x40 mm sections and horizontal 10 mm thick 40x40 mm sections were cut from core depths indicated in Table 4.

All specimens were impregnated with resin to facilitate the preparation of one polished slab and one thin section. Figure 4 shows the general orientation of vertical and horizontal thin section specimens. The vertical specimen (A) nearest the concrete surface (0-60 mm) was cut first to enable the horizontal section (B) at 20 mm to be cut more easily. Thereafter at greater depths, the horizontal sections were cut first (C, D, E, etc), followed by vertical sections.

3.3 Petrographic Examination of Hardened Concrete

A total of 65 polished slabs and thin sections from the seawall blocks were examined (Table 4). Initial examination of polished slabs was made using a low power Olympus SZ40 stereo microscope with zoom function. Detailed thin section examination was subsequently made using an Olympus BH-2 polarizing microscope. Selected photomicrographs were taken using a Canon 20D digital camera attached to the polarizing microscope.

Detailed polished slab and petrographic descriptions are given in Appendix 1.

3.4 Identification of Alkali-Aggregate Reaction in Thin Sections and Polished Slabs

Identification of AAR in thin sections followed the procedures outlined in the RILEM AAR1 method and ASTM C 856 (1995). In addition, reference was made to thin sections of

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alkali aggregate reaction in Hong Kong concrete prepared by Geomaterials Research Services Ltd. and held in the HKGS archive. These reference materials were used in an in-house CEDD course given on identification of AAR by Dr W.J. French in 1998. Reference was also made to three reports describing AAR in Hong Kong concrete (Sewell & Campbell, 2001), a recent review on prevention of alkali silica reaction in Hong Kong concrete (Chak & Chan, 2005), and to a standard reference text on concrete petrography (St. John et al, 1998).

In addition to petrographic methods, the uranyl-acetate test (Natesaiyer & Hover, 1988) was employed for detecting the presence of alkali-silica gel. Alkali-silica gel will fluoresce bright greenish-yellow under shortwave (254 nm) ultraviolet (UV) light when treated with uranyl-acetate solution. The test procedure is described in the Annex to ASTM C 856 (1995) but is regarded as an ancillary, rather than diagnostic, test for the identification of alkali-silica gel. This is because ettringite and carbonated areas of concrete may similarly fluoresce. Fluorescence due to carbonation is generally exhibited by a relatively uniform distribution through the cement paste or concentration along concrete surfaces or cracks exposed to the atmosphere.

In order to distinguish alkali-silica gel from other possible fluorescent materials, such as ettringite and carbonated areas, one polished slab specimen known to contain alkali-silica gel in thin section was subject to the uranyl-acetate test. Areas of gel from thin section were sketched out (Plate 3a) and then compared with a corresponding polished slab treated with uranyl-acetate solution (Plate 3b). Bright greenish-yellow fluorescence under UV light was found to correlate strongly with the presence of alkali-silica gel, particularly along aggregate margins. Weak green fluorescence was found to be associated with cracks and voids infilled with ettringite, and very faint green fluorescence corresponded with the carbonated areas of the cement paste. Results of the uranyl-acetate test for selected specimens (Table 2) from the seawall blocks are given in Table 5 and illustrated in Plate 4.

3.5 Distress Measurement of Seawall Blocks

Detailed *in situ* measurements were carried out in order to investigate the pattern of surface cracking in the distressed seawall blocks. A preliminary investigation of volumetric expansion of the distressed seawall blocks was also carried out. However, as only the upper portion of the distressed seawall blocks were exposed and therefore available for measurement, these surveys provided only a qualitative assessment of the overall deformation.

3.5.1 Crack Mapping

The surface crack mapping exercise was conducted for the six distressed seawall blocks between December 2005 and February 2006. An overview of the seawall blocks is shown in Plate 1.

The crack patterns on the upper and landward faces of the six seawall blocks (WW3, WW5, WW9A, WW9B, WW34 & WW35) which contained no PFA, were mapped on tracing paper (Plates 5 & 6). The seaward face of the seawall blocks was not mapped due to lack of safe access to carry out the mapping work. The control seawall block (WW28) showed no appreciable crack pattern and hence was not mapped. A ruler (Plate 7) and a feeler gauge

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were used to measure the cracks in the six seawall blocks.

3.5.2 Deformation Survey

The preliminary deformation survey comprised measurements of the upper portions of the distressed seawall blocks in comparison with adjacent control blocks in order to obtain general information on the pattern of expansion. The initial part of the survey involved calibration measurement of various dimensions of the non-deformed seawall blocks, including leveling, alignment and inclination. This was followed by measurements of the distressed seawall blocks (Plate 8). Details of measurement procedures and data tables are given in Appendix 2.

4. PETROGRAPHIC EXAMINATION OF CONCRETE CORE SAMPLES

4.1 General

The coarse and fine aggregates in all samples generally comprise two main types: (a) porphyritic fine-grained granite, weakly recrystallised, displaying a typical hypidiomorphic granular texture, and (b) fine- to medium-grained granite, weakly altered, containing perthitic orthoclase and microcline, along with plagioclase and aggregates of biotite. Granophyric texture is seen in some aggregate fragments indicating crystallisation under low pressure. Occasional tuffisite veins and rare fractures infilled with granulated material (cataclasite) are present within aggregates of both the coarse and fine fractions, and sparse mafic rock fragments (quartz microdiorite) are also present. The sand fraction comprises fragments of granite and single grains of feldspar and quartz. Some rare single grains of strained quartz are present in the sand fraction.

4.2 Control Seawall Block

4.2.1 WW28

Three vertical and four horizontal core specimens from depths varying from 0 mm to 250 mm were examined (Table 2). One horizontal slab specimen from a depth of 240-250 mm, and two core specimens from a depth of 330 mm were tested with uranyl-acetate solution (Table 4).

(i) Polished Slabs Both the coarse (10-20 mm) and fine (5-8 mm) aggregates are generally composed of porphyritic fine-grained granite and fine- to medium-grained granite. The sand fraction is composed mostly of granitic rock fragments, quartz and feldspar crystals. Air voids are present in most specimens examined and these appear to be either resin-infilled, or unfilled. Occasional ring cracks surround aggregate fragments and there are minor cracks in the grey cement paste. Some of these cracks may also be either resin-infilled or unfilled.

(ii) Thin Sections In addition to the coarse and fine-grained granite aggregates, rare fragments of tuffisite (Plate 9) are present in the cement paste, along with minor accidental inclusions of steel fibre. Fly-ash (PFA) spheres are scattered throughout the cement paste in all of the examined specimens. The aggregate fragments are sometimes

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surrounded by fine cracks, but these are not obviously infilled. No alkali-silica gel or ettringite within cracks was observed in any of the thin sections examined. Air voids and minor cracks are mainly infilled with resin. All except one specimen showed approximately 10% carbonation of the cement paste. However, in many thin sections, carbonation of the cement paste appears to be concentrated along the edges of the slides. Much of the carbonation, therefore, probably occurred after recovery of the concrete core.

(iii) Uranyl-Acetate Test A very dull green fluorescence was observed from some aggregate fragments in the tested specimen (Plate 4a), but overall, there was very little or no fluorescence emitted from the cement paste.

4.3 Distressed Seawall Blocks

4.3.1 WW3

Three vertical and three horizontal core specimens from depths varying from 0 mm to 240 mm were examined (Table 2). One horizontal slab from a depth of 170-180 mm, and two core specimens from depths of 250 mm and 340 mm respectively, were tested using uranyl-acetate solution (Table 4).

(i) Polished Slabs The coarse (10-20 mm) aggregate fraction in these specimens is composed of porphyritic fine-grained granite (some weakly recrystallised), fine- to medium-grained granite and mafic rock fragments, whereas the fine (5-8 mm) aggregate comprises porphyritic fine-grained granite and mafic rock fragments. A few minor (<0.1 mm) cracks are seen in the cement paste, and occasionally larger (0.5-2 mm) cracks. Ring cracks surrounding aggregate fragments occur locally and appear to be infilled with white fibrous material. Air voids are common in most specimens and also appear to be infilled with white fibrous material.

(ii) Thin Sections Both the coarse (10-20 mm) and fine (5-8 mm) aggregate fractions are composed mostly of porphyritic fine-grained granite (some weakly recrystallised) and fine- to medium-grained granite. The sand fraction is composed of mainly granitic rock fragments, quartz and feldspar. Overall, approximately 5-10%, and occasionally up to 20%, of the cement paste is carbonated, and carbonation generally is concentrated along cracks and along the edges of the slides. Much of the carbonation, therefore, probably started after recovery of the concrete core. Cracks are ubiquitous in the cement paste, and may surround aggregate fragments in the form of a ring crack. Ring cracks, cracks in the cement paste, and air voids are invariably infilled with ettringite. The ettringite is typically in the form of fine crossed acicular crystals (Plate 10), or curtain-like groups of crystals (Plate 11), which may be oriented perpendicular to the crack or air void walls. Layered material infilling some cracks appears to be altered alkali-silica gel. Minor steel fibre contaminants are present in some specimens.

(iii) Uranyl-Acetate Test A dull green fluorescence was observed from most of the cement paste in the tested specimen, whereas moderate greenish yellow fluorescence was emitted from thin cracks in the cement paste and from the margins of a few aggregate fragments (Plate 4b). Overall, a moderate amount of fluorescent material was observed in the tested specimen.

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4.3.2 WW5

Four vertical and five horizontal core specimens from depths varying from 0 mm to 1020 mm were examined (Table 2). One horizontal slab from a depth of 240-250 mm, and one core specimen from a depth of 330 mm were tested with uranyl-acetate solution (Table 4).

(i) Polished Slabs The coarse (10-20 mm) and fine (5-8 mm) aggregate fractions are composed of porphyritic fine-grained granite, fine- to medium-grained granite and mafic rock fragments. The sand fraction is composed of occasional granitic rock fragments, quartz and feldspar crystals, and sparse mafic rock fragments. There are abundant ring cracks surrounding aggregate fragments and these appear to be infilled with possible alkali-silica gel or ettringite. Air voids are present, and are commonly infilled, possibly with ettringite, or alkali-silica gel. When wet, the cement paste is grey in colour.

(ii) Thin Sections Both the coarse (10-20 mm) and fine (5-8 mm) aggregates include porphyritic fine-grained granite which is weakly recrystallised, fine- to medium-grained granite, and fine-grained granite, and quartz microdiorite. Granitic rock fragments, quartz and feldspar crystals make up the main components of the sand fraction. There are occasional fragments of steel fibre. Up to 20% of the cement paste is carbonated. Ettringite appears to be the dominant material infilling air voids (Plate 12) and cracks in the cement paste, and in ring cracks surrounding aggregate fragments. However, material resembling dried alkali-silica gel also appears to emanate into some cracks within the cement paste from occasional tuffisite veins within granite fragments. The alkali-silica gel displays a desiccation crack pattern and granular birefringent material within the aggregate fragment may represent an intermediate stage in gel formation (Plates 13 & 14). There is also evidence for possible multiple phases of gel deposition later disrupted by growth of ettringite needles (Plate 15).

(iii) Uranyl-Acetate Test Bright greenish yellow fluorescence was observed in cracks in the cement paste and in some selected aggregates (Plate 4c). Some infilled air voids also showed bright greenish yellow fluorescence. Overall, there was abundant fluorescent material observed in the tested specimen.

4.3.3 WW9A

Duplicate core specimens were taken to investigate any possible vertical and horizontal deleterious variations within the concrete seawall block. Five vertical and six horizontal specimens from depths varying from 0 mm to 2070 mm were taken from one corehole (CH3, Table 4), whereas three vertical and three horizontal specimens from depths varying from 0 mm to 250 mm were taken from the duplicate corehole (CH4, Table 4). One horizontal polished slab specimen from a depth of 2020-2030 mm, and four core specimens from depths of 30 mm, 200 mm, 1150 mm and 1850 mm were tested with uranyl-acetate solution (Table 5).

(i) Polished Slabs The coarse (10-20 mm) and fine (5-8 mm) aggregates in specimens comprise porphyritic fine-grained granite and fine- to medium-grained granite, along with a few mafic rock fragments. The sand fraction appears to be mostly composed of granitic rock fragments, quartz and feldspar crystals. A few minor (<0.1 mm) cracks in the

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cement paste and ring cracks surrounding aggregates appear to be infilled with ettringite, and possibly alkali-silica gel. Air voids are common and often bordered with fibrous material resembling ettringite. The cement paste is generally light grey when wet.

(ii) Thin Sections Both the coarse (10-20 mm) and fine (5-8 mm) fractions comprise porphyritic fine-grained granite (some weakly recrystallised), fine- to medium-grained granite and quartz microdiorite. The sand fraction is dominantly granitic, with quartz and feldspar crystals, and occasional mafic rock fragments. Approximately 10-15% of the cement paste is carbonated, but in two specimens this may vary between 20% and 80%. Cracks in the cement paste, and some ring cracks around aggregates, are partly infilled with fine needles of ettringite. The larger air voids are bordered with ettringite needles, which commonly occur in radiating clusters (Plate 16) growing out from the walls, whereas the smaller air voids are either completely infilled with ettringite, or unfilled. There are minor steel fibre contaminants in the cement paste. Trace amounts of alkali-silica gel are present in some cracks, and in some air voids there is evidence for possible multiple phases of gel deposition interrupted by growth of ettringite (Plates 17 & 18). The birefringent layers of gel in the air voids (e.g. Plate 18) suggest that it is slightly crystallised and therefore the gel may be relatively old (St John et al, 1998).

(iii) Uranyl-Acetate Test Moderate to bright greenish yellow fluorescence was displayed by many aggregates in the tested specimen (Plate 4d), although the majority of the cement paste showed a dull green fluorescence. Overall, the amount of fluorescent material was judged to be moderate.

4.3.4 WW9B

Three vertical and three horizontal core specimens from depths varying from 0 mm to 250 mm were examined (Table 4). One vertical polished slab specimen from a depth of 240-300 mm, and two core specimens from depths of 0.3-0.4 m and 0.45 m, respectively, were tested with uranyl-acetate solution (Table 5).

(i) Polished Slabs Coarse (10-20 mm) aggregates are mostly composed of porphyritic fine-grained granite and fine- to medium-grained granite, but there are occasional foliated mafic fragments. The fine (5-8 mm) aggregate is composed mostly of porphyritic fine-grained granite, fine-grained granite, mafic rock fragments and occasional fine- to medium-grained granite. The sand fraction consists of mostly granitic rock fragments, quartz and feldspar crystals. Cracks in the cement paste commonly connect with aggregate fragments and appear to be infilled with possible ettringite or alkali-silica gel. Air voids are bordered with possible ettringite.

(ii) Thin Sections The coarse (10-20 mm) aggregates are composed of mainly fine- to medium-grained granite, porphyritic fine-grained granite (some weakly recrystallised), and quartz microdiorite. The fine (5-8 mm) aggregates are composed of fine- to medium-grained granite, porphyritic fine-grained granite and occasional fine-grained granite and quartz microdiorite. Sand is composed of granitic rock fragments, quartz and feldspar crystals. Rare fractures within the granite aggregates are infilled with granulated quartz-rich material resembling cataclasite (Plate 19). Close to the surface of the concrete, approximately 40% of the cement paste is carbonated. The degree of carbonation appears to reduce at deeper

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levels in the concrete and is mainly concentrated along cracks. Cracks in the cement paste are mainly resin-filled, and a few air voids may be infilled with ettringite. Trace amounts of layered alkali-silica gel are present in cracks associated with rare tuffisite and cataclasite in granite aggregates, and in air voids in the cement paste. Minor fragments of accidental steel fibre are present in the cement paste.

(iii) Uranyl-Acetate Test Moderate greenish yellow fluorescence was displayed by several aggregates in the cement paste, whereas the majority of the cement paste showed a dull green fluorescence (Plate 4e). Overall, the amount of fluorescent material was judged to be moderate.

4.3.5 WW34

Four vertical and five horizontal core specimens from depths varying from 0 mm to 1070 mm were examined (Table 2). One horizontal polished slab specimen from a depth of 1060-1080 mm, and one core specimen from a depth of 0.6 m were tested with uranyl-acetate solution (Table 4).

(i) Polished Slabs Most of the coarse (10-20 mm) aggregates are composed of porphyritic fine-grained granite, fine- to medium-grained granite and rare mafic fragments. Fine aggregates (5-8 mm) are composed of porphyritic fine-grained granite and rare mafic fragments. In the near surface specimens, the granite aggregates appear slightly altered. The sand fraction is dominated by granitic rock fragments, quartz and feldspar crystals. Cracks in the cement paste are most pronounced in the shallow depth specimens and commonly surround aggregate fragments. These appear to be infilled with fibrous material resembling ettringite. Air voids are ubiquitous, and also appear to be infilled with ettringite. The cement paste is a faint pink colour when wet.

(ii) Thin Sections The coarse (10-20 mm) aggregate fraction is composed mostly of porphyritic fine-grained granite, and fine- to medium-grained granite, both of which are weakly altered, and quartz microdiorite. There is minor strained quartz in some granite fragments. Fine (5-8 mm) aggregates are composed of fine- to medium-grained granite with altered feldspar, and strained quartz and feldspar. The sand fraction is composed of granite fragments, quartz and feldspar crystals. The cement paste is well-hydrated (W/C = 0.55-0.60). A large proportion (up to 60%) of the cement paste is carbonated. Ring cracks surround aggregate fragments and connect with air voids. The ring cracks are commonly infilled with acicular crystals of ettringite growing perpendicular to the crack walls. Air voids are also bordered, and commonly completely infilled, with ettringite. There are minor inclusions of steel fibre in the cement paste. Trace layered alkali-silica gel is present in minor cracks and lining air voids in the cement paste.

(iii) Uranyl-Acetate Test Bright greenish yellow fluorescence was displayed by several aggregates in the cement paste and from cracks within the cement paste (Plate 4f). The remainder of the cement paste showed a dull green fluorescence. Overall, there was abundant fluorescent material in the tested specimens.

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4.3.6 WW35

Duplicate core specimens were taken to investigate any possible vertical and horizontal deleterious variations within the concrete seawall block. Five vertical and six horizontal specimens from depths varying from 0 mm to 2070 mm were taken from one corehole (CH1), whereas three vertical and three horizontal specimens from depths varying from 0 mm to 250 mm were taken from the duplicate corehole (CH2, Table 4). One horizontal polished slab and four specimens from duplicate coreholes at depths of 0.34 m, 0.38 m, 0.42 m and 0.48 m were tested with uranyl-acetate solution (Table 5).

(i) Polished Slabs The coarse aggregates are composed of mainly porphyritic fine-grained granite and fine- to medium-grained granite, while the fine aggregates are composed mostly of porphyritic fine-grained granite and occasional fine- to medium-grained granite and mafic fragments. The sand fraction is composed of granitic rock fragments, quartz and feldspar crystals. Some minor cracks in the cement paste and many ring cracks surrounding aggregate fragments (and occasional cracks within aggregates) may be infilled with possible ettringite or alkali-silica gel. Air voids appear to be infilled with possible ettringite. The cement paste is light grey when wet.

(ii) Thin Sections Both coarse (10-20 mm) and fine (5-8 mm) aggregates are composed of porphyritic fine-grained granite (some weakly recrystallised) and fine- to medium-grained granite. Occasional tuffisite veins (Plates 20, 21 & 22) are present within the coarse and fine granitic fragments and there are minor fragments of quartz microdiorite. Microscopic cracks (<0.01 mm) infilled with alkali-silica gel are sometimes seen emanating from tuffisite veins into the cement paste (e.g. Plate 21). The weakly birefringent granular material seen infilling the crack within the tuffisite (Plate 22) is possibly crystalline gel. The sand fraction is composed of small (<1 mm) granitic rock fragments, quartz and feldspar crystals. The cement paste is variously carbonated (5-20%), but is commonly localised around cracks. There are many minor cracks in the cement paste and ring cracks surrounding aggregate fragments which are commonly completely infilled with ettringite needles. There are multiple layers of alkali-silica gel lining some air voids (Plate 23), some of which have been subsequently disrupted by growth of ettringite (Plate 24). Some microscopic (<0.01 mm) cracks in the cement paste appear to show an abrupt transition from being infilled alkali-silica gel, to being infilled with ettringite as they broaden (Plates 25 & 26). There is also evidence of cross-cutting relationships with cracks infilled with layered alkali-silica gel being cross-cut by cracks infilled with ettringite (Plate 27). Other cracks lined with layers of alkali-silica gel appear to be either open, or partly infilled with plugs of opaque material (Plate 28). There are minor accidental inclusions of steel fibres in the cement paste.

(iii) Uranyl-Acetate Test Bright greenish yellow fluorescence was observed from cracks around aggregates, and from cracks and air voids within the cement paste (Plate 3). Several aggregates in the cement paste also displayed bright greenish yellow fluorescence, particularly from marginal areas. The majority of the cement paste displayed a dull green fluorescence. Overall, there was abundant fluorescent material in the tested specimens.

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5. CRACK MAPPING AND DEFORMATION SURVEY OF SEAWALL BLOCKS

5.1 Crack Mapping

The surface crack patterns of both top and landward faces of the six distressed seawall blocks are shown in Figures 9-14.

Following the practice of Geomaterial Research Services Ltd. in CLP (2002), the cracks can be divided into three scales: (i) macrocracking (> 1 mm wide), (ii) fine cracking (between 1.0 and 0.1 mm wide), and (iii) microcracking (<0.1 mm wide). Microcracking is generally only discernible in thin section. Two different styles of cracking can also be distinguished: (a) map pattern cracking and (b) longitudinal cracking.

Map pattern cracking is well-developed in all of the distressed seawall blocks, but at different scales and densities. Large (>250 mm wide) polygonal cracks are developed in WW3, WW5, WW9A, and WW9B, whereas generally smaller (20-200 mm wide) and denser polygonal cracks are developed in WW34 and WW35. WW35 displays the highest density of map pattern cracking which appears on two scales: a medium scale with diameter of 200 mm and a fine scale with diameters generally less than 20 mm. Overall, the seawall blocks are ranked in order of decreasing map pattern crack density as follows: WW35, WW34, WW3, WW5, WW9A and WW9B.

Longitudinal macrocracking in the *x*-direction is best developed in WW5, WW9A, WW34 and WW35. The macrocracks generally connect with the twin corners of the interlocking notches across the top faces of the seawall blocks. Two main longitudinal macrocracks on the top face are observed, but sometimes a third longitudinal crack (e.g. WW34) is present. Longitudinal cracks in the *x*-direction are also prominent on the landward faces of WW3, WW5, WW9B, and WW34.

Almost all the distressed seawall blocks display well-developed longitudinal cracks in the *y*-direction. These cracks generally traverse across both the landward and top faces of the seawall blocks and intersect with the *x*-direction longitudinal cracks. In WW9A, WW9B, WW34 and WW5, the *y*-direction longitudinal cracks are roughly equally spaced. In some seawall blocks (e.g. WW3, WW5, WW9A), the *y*-direction longitudinal cracks may connect continuously across the both vertical and horizontal faces, whereas in other blocks (e.g. WW34, WW35), they are discontinuous.

5.2 Deformation Survey

Preliminary measurements of leveling (Appendix 2) suggest that the upper portions of all monitoring blocks have experienced vertical expansion when compared with the adjacent control blocks. The magnitude of expansion ranges from 6 mm to 25 mm. The descending order of vertical expansion of the blocks is: WW3, WW35, WW9B, WW5, WW9A, WW34 and WW28.

Preliminary measurements of alignment (Appendix 2) suggest that the upper portions of all seawall blocks have experienced horizontal expansion. Three seawall blocks show expansion in the landward direction whereas four blocks show contraction, when compared with the adjacent control blocks. The descending order of landward expansion is WW9A,

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WW3 and WW9B, with the amount of expansion ranging from 2 mm to 3 mm. The upper portions of all seven blocks appear to have expanded in the seaward direction when compared with adjacent control blocks. The descending order of seaward expansion is WW35, WW34, WW9A, WW5, WW9B, WW28 and WW3. The amount of expansion ranges from 4 mm to 40 mm (equivalent to a 0.24% to 2.81% change) with an average expansion of 15 mm.

The upper portions of four seawall blocks appear to have experienced a bulging effect. In descending order of bulging, these are WW34, WW3, WW5 & WW35. The average bulging angles ranged from 0.14 to 0.4 degrees, which are considered insignificant. The other distressed blocks (WW9B, WW9A) did not experience a bulging effect.

Preliminary estimates of the overall volumetric expansion based on the measured upper portions of all seven monitored blocks range from 0.20% to 3.94%. The descending order of overall expansion is WW3, WW35, WW9B, WW5, WW9A, WW34 and WW28.

6. DISCUSSION

The findings of the petrographic study reported here strongly suggest the participation of alkali-silica gel and secondary ettringite in the distress of the concrete seawall blocks at Tsang Tsui Ash Lagoon. Thus, they are in general agreement with the conclusions of an earlier preliminary petrographic study on one of the distressed seawall blocks (WW34) by Geomaterials Research Services Ltd. (CLP, 2002).

Petrographic methods, supported by uranyl-acetate testing of polished slabs, have been used to unambiguously identify alkali-silica gel in approximately one third of the specimens (Appendix 1), but the alkali-silica gel generally is much less abundant than fibrous crystalline material resembling ettringite. The alkali-silica gel occurs mainly as thin continuous layers on the sides of cracks in the cement paste (Plate 29) and as rims on the linings of some entrapped air voids (Plate 15). Layered alkali-silica gel is also seen filling some cracks in aggregate fragments (e.g. Plates 25 & 27), and ring cracks surrounding aggregate fragments (e.g. Plate 25). The alkali-silica gel commonly displays conchoidal drying cracks (e.g. Plate 13), and may vary in texture from granular birefringent material in cracks within aggregates (e.g. Plate 14), to isotropic clear and dark gel, and weakly birefringent crystallised gel within cracks and air voids (e.g. Plate 18). The appearance of crystallised alkali-silica gel suggests that the gel is relatively old (c.f. St John et al, 1998).

There is evidence in a few specimens for multiphase deposition of alkali-silica gel. In a thin section from WW9A (Plates 17 & 18), alkali-silica gel has been deposited within an air void in stages, separated by episodes of drying, cracking and crystallisation. The conchoidal drying cracks in the alkali-silica gel appear to have formed after an early phase of gel deposition, and in later phases, the cracks may have acted as conduits for further gel movement. Differences in the degree of alkali-silica gel crystallisation, and possibly composition, are indicated by differences in birefringence shown by the gel layers (Plate 18).

The alkali reactive materials appear to be mainly microcrystalline and cryptocrystalline quartz in rare thin (1 mm) tuffisite veins (Plates 13, 14, 20, 21 & 20), and also possibly granulated quartz-rich material (cataclasite) infilling rare fractures, within granite aggregate fragments (Plate 19). Both materials have been previously reported as potentially reactive

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components from Lamma Quarry rock (Geomaterial Research Services Ltd. 1993). However, in the specimens examined, tuffisite veins and cataclasite-filled fractures within granite aggregate fragments are present in extremely small volume (typically <0.1%) so as to make the aggregate as a whole relatively non-reactive with respect to AAR.

The most notable occurrences of alkali-silica gel in thin section were observed in WW5, WW34 and WW35 (see Sections 3.3.2, 3.3.5 and 3.3.6), typically from horizontal sections from core depths exceeding 135 mm. Specimens from these seawall blocks also displayed the brightest greenish yellow fluorescence when subject to the uranyl-acetate test (Table 5). Tested core specimens from WW3, WW9A and WW9B also displayed moderate greenish yellow fluorescence indicating the presence of alkali-silica gel. There was no unambiguous identification of alkali-silica gel in the control sample (WW28) and this sample also showed the weakest greenish yellow fluorescence when treated with uranyl-acetate solution (Table 5).

The dominant material infilling cracks in cement paste, ring cracks around aggregate fragments, and entrapped air voids in the concrete of all severely distressed seawall blocks is secondary ettringite. In order for ettringite to form in concrete, moisture gradients are required to facilitate the transport of sulphate ions. This applies to the formation of primary ettringite during hydration of tricalcium silicate, and to growth of secondary ettringite in hardened concrete (St John et al, 1998). In core hand specimens, the ettringite occurs as a white fibrous crystalline material surrounding many aggregate fragments. Acicular ettringite needles are observed in almost all thin sections from distressed seawall blocks growing into cracks within the cement paste (Plate 26), ring cracks around aggregate fragments (Plates 10 & 25) and entrapped air voids (Plates 15 & 24). Radiating clusters of ettringite needles (Plate 16) are commonly seen on the margins of air voids growing out from the cement paste. Many of the entrapped air voids in the distressed seawall blocks are almost completely filled with ettringite crystals (Plate 12).

Several specimens yield evidence to suggest that some ettringite growth in cracks and air voids may have occurred following deposition of the alkali-silica gel. In thin sections from WW35, layers of alkali-silica gel filling ring cracks around aggregate fragments (Plate 25) and cracks in the cement paste (Plates 26 & 27a), appear to have been disrupted by later growth of ettringite. In particular, growth of ettringite seems to have exploited, and possibly enlarged, cracks previously filled with alkali-silica gel (Plates 26 & 27b). In these examples, coarse ettringite crystals (Plate 28) appear to truncate the alkali-silica gel in cracks abruptly. Further evidence of alkali-silica gel disruption by later growth of ettringite is shown by infillings of some entrapped air voids (Plates 15, 17 & 24). In these examples, radiating clusters of ettringite needles growing out of the cement paste have deformed pre-existing layers of alkali-silica gel.

The growth of secondary ettringite is known to be influenced by high curing temperatures (French, 1991). For example, curing temperatures above 70ºC exceed the known stability limit of ettringite (Stark et al, 1990). At these elevated temperatures, sulphate in the concrete will exist in a monosulphate phase rather than in ettringite. After hardening of the concrete, ettringite can reform in the presence of moisture and this may lead to growth of secondary ettringite in the cement paste. Where this process leads to expansion and possible cracking of the cement paste, mortar and concrete, it is known as delayed ettringite formation (DEF). The high curing temperatures recorded for all distressed seawall blocks, except for

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WW3, (see Section 2, Table 2), lie well above the stability limit of ettringite and this may explain the relative abundance of secondary ettringite in these seawall blocks.

Shimada et al, (2005) noted that there is considerable controversy surrounding DEF and its relationship to expansion of concrete. One of the contentious issues relates to whether or not alkali-silica reaction is a necessary precursor to DEF-related expansion. The strongest evidence opposing ASR as a prerequisite for DEF-related expansion comes from laboratory experiments on mortars and concretes made from non-reactive aggregate (e.g. Fu et al, 1997). These have shown that DEF-related expansion can occur independently of ASR. On the other hand, Brown & Bothe (1993) have argued that depletion of hydroxyl ions from pore solutions by ASR may provide conditions amenable to ettringite formation. Such a view is generally supported by French (1991) who notes that locally, in the presence of moisture passing through the concrete, complete replacement of alkali-silica gel by ettringite in the cement paste may occur. The petrographic evidence presented in Plates 25, 26 & 27 showing an abrupt transition from alkali-silica gel to ettringite in cracks within the cement paste suggests a close association between alkali-silica gel and DEF.

A second major controversy surrounding DEF and its relationship to expansion of concrete concerns whether or not ettringite growth in gaps at the aggregate-paste interface is a cause (crystal growth pressure hypothesis; Heinz & Ludwig, 1986) or a consequence (paste expansion hypothesis; Johansen et al, 1993) of expansion. Evidence for possible exploitation and enlarging of some alkali-silica gel-infilled cracks by replacement/growth of ettringite (e.g. Plate 27b) suggests that expansion due to crystal growth pressure may have played a role. However, the presence of alkali-silica gel infilling gaps at the aggregate paste-interface (Plates 25 & 27a & b) suggests that some paste expansion may also have occurred prior to deposition of alkali-silica gel.

Concrete mix designs have an important influence on the potential for DEF. For example, the molar ratio of SO_3/Al_2O_3 generally needs to be greater than 0.55 for significant DEF to occur, while low water/cement ratios also appear to promote DEF (St John et al, 1998). WW35 shows the highest density of cracking of all monitored seawall blocks (Figure 10). In addition to alkali-silica gel, WW35 also has the highest concentration of ettringite in thin section (Appendix 1) and the second highest volumetric expansion based on preliminary measurements of deformation (Appendix 2). Mix design records (CLP, 1990c) reveal that WW35 concrete has a relatively low (0.47) water/cement ratio and moderate (0.50) SO_3/Al_2O_3 ratio (Table 2). Thus, the mix designs in the monitored seawall blocks, particularly those containing OPC, may possibly have favoured DEF.

The appearance of coarse ettringite crystals infilling some cracks in the cement paste (Plate 28), as opposed to fine curtain-like growth of ettringite (Plate 11) is indicative of an ageing process known as "Ostwald ripening" (Skalny et al, 1996). This promotes the dissolution of fine crystals of ettringite by pore solutions and subsequent recrystallisation as relatively large crystals in spaces available. Opaque material intermittently filling some cracks lined with alkali-silica gel (Plate 29) suggests that some of the cracks may have remained open, facilitating the movement of pore solutions. The composition of this opaque material has not been determined, but its occurrence in open cracks suggest that it might be a secondary oxide precipitate.

The crack mapping and preliminary deformation surveys (Appendix 2) have provided

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insight into the development of distress in the monitored seawall blocks. The map pattern cracking displayed by the distressed seawall blocks is typical of that reported for AAR-affected concrete (Grattan-Bellow & Mitchell, 2002). Such a pattern develops in response to expansion of the cement paste as the alkali-silica or alkali-carbonate reactive gel is exuded from the reactive aggregate into cracks and cavities. However, a similar crack pattern has also been shown to develop in concrete undergoing only DEF (Johansen et al, 1993), although it has been suggested (St John et al, 1998) that ring fracturing around aggregates distinguishes DEF- from AAR-related cracking. The presence of alkali-silica gel and widespread secondary ettringite in cracks and voids in the cement paste, together with ring fissuring around aggregates, suggests therefore that map pattern cracking in distressed seawall blocks at Tsang Tsui Ash Lagoon is a consequence of both AAR- and DEF-related expansion.

In addition to map pattern cracking, longitudinal cracks have developed in the distressed seawall blocks. However, the cause of longitudinal cracking as opposed to map pattern cracking is uncertain and requires further investigation. One possibility is that longitudinal cracks developed during expansion due to stresses induced by the constraining effects of adjacent non-deformed seawall blocks (i.e. structural cracking).

Hot daytime temperatures during concreting (up to 29°C), curing with seawater, and a high internal temperature rise (up to 61°C) during curing, are likely to have contributed to increased potential for DEF in the monitored seawall blocks. The slightly reduced expansion shown by the upper portions of seawall blocks WW5 (2.80%), WW9A (1.74%) and WW9B (2.81%) and WW34 (0.82%), compared to WW3 and WW35, could be due to variety of reasons, including differences in cement type, water/cement ratio, casting and curing conditions. It is known that WW9A and WW9B contain sulphate-resisting cement which is thought to reduce the susceptibility to sulphate attack and hence the possibility of deterioration. WW5 and WW34 have much higher water/cement ratios and experienced less rise in temperature during concrete curing than the other distressed blocks (Table 2), which may have helped to reduce the potential for DEF. The upper portion of control block (WW28) shows the least expansion (0.20%) suggesting that addition of PFA may greatly reduce the overall potential for concrete deterioration.

7. CONCLUSION

The following general conclusions can be made with respect to the petrographic study of distressed seawall blocks at Tsang Tsui Ash Lagoons:

(a) The aggregate used in concrete production comprises mainly weakly recrystallised porphyritic fine-grained granite and fine- to medium-grained granite containing rare thin (1 mm) veins of tuffisite and microfractures infilled with granulated quartz (cataclasite). Sporadic fragments of quartz microdiorite are also present.

(b) Small amounts of alkali-silica gel are present within cracks and entrapped air voids in many of the distressed seawall blocks. The gel appears to have been deposited in multiple phases, and to have formed relatively early in the life of the concrete.

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(c) The alkali reactive material within the aggregate appears to be mainly microcrystalline to cryptocrystalline quartz associated with tuffisite veins, and possibly granulated quartz associated with cataclasite.

(d) Ettringite is present in abundance infilling cracks and voids in the cement paste, and ring cracks surrounding aggregate fragments, of the distressed seawall blocks. Some ettringite growth appears to have post-dated deposition of alkali-silica gel.

The following general conclusions can be made with respect to the preliminary deformation survey of the distressed seawall blocks at Tsang Tsui Ash Lagoons:

(a) The upper portions of all of the monitored seawall blocks have apparently experienced volumetric expansion. The greatest expansion (3.94%) is shown by WW3 and the least expansion (0.20%) by the WW28.

(b) The seawall blocks made of OPC (without PFA) show greater expansion than seawall blocks made of SRC (without PFA). The seawall block made of OPC with PFA shows significantly less expansion than seawall blocks without PFA.

(c) Surface cracking in the distressed seawall blocks consists principally of (i) map pattern cracking, and (ii) longitudinal macrocracking. Map pattern cracking appears to have been caused by expansion due to AAR and DEF. The origin of longitudinal macrocracking is uncertain and requires further investigation.

The following general conclusions can be made with respect to mix design, casting and curing conditions of monitored seawall blocks at Tsang Tsui Ash Lagoons:

(a) The use of SRC in the concrete appears to have reduced the potential for DEF.

(b) DEF may have been facilitated by: (i) elevated ambient daytime temperatures at the time of casting, and (ii) unusually high curing temperatures.

(c) Relatively low water/cement ratios and moderate (0.50) SO_3/Al_2O_3 ratios in concrete may have increased the potential for DEF.

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8. KEY FINDINGS

(a) The granite aggregate used in the production of the concrete seawall blocks at Tsang Tsui Ash Lagoons appears to be largely non-reactive with respect to alkali-aggregate reaction. However, within the aggregate, rare thin (1 mm) veins of tuffisite and microfractures filled with cataclasite contain potential alkali reactive materials.

(b) Cracking and expansion in distressed seawall blocks at Tsang Tsui Ash Lagoon appears to be the result of a small amount of alkali-aggregate reaction and a large amount of delayed ettringite formation.

(c) The use of PFA in the concrete appears to have greatly reduced the potential for concrete deterioration.

9. REFERENCES

ASTM C856-95 (1995). Standard Practice for Examination and Sampling of Hardened Concrete. Philadelphia, USA.

Brown, P.W. & Bothe, J.V. (1993). The Stability of Ettringite. Advances in Cement Research, Vol. 5, pp 47-63.

Chak, Y.H. & Chan, Y.C. (2005). The 2004 Review on Prevention of Alkali Silica Reaction in Concrete. GEO Report No. 167. Geotechnical Engineering Office, Civil Engineering and Development Department, The Government of the Hong Kong Special Administrative Region. 77 p.

China Light & Power Ltd. (CLP) (1990a). PFA Concrete Studies. 1988 - 1998. Volume 1. Principal Report and Appendix 1. China Light and Power Company Limited.

China Light & Power Ltd. (CLP) (1990b). PFA Concrete Studies. 1988 - 1998. Volume 2: Appendix 2. Report on Site and Laboratory Procedures. China Light and Power Company Limited.

China Light & Power Ltd. (CLP) (1990c). PFA Concrete Studies. 1988 - 1998. Volume 7: Appendix 7. Fresh and Early-age Properties. China Light and Power Company Limited.

China Light & Power Ltd. (CLP) (2002). PFA Concrete Studies. 1988 - 2000. Final Report. China Light and Power Company Limited.

French, W.J. (1991). Concrete Petrography - A Review. Quarterly Journal of Engineering Geology, Vol. 24, pp 17-48.

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Fu, Y., Xie, P., Gu, P. & Beaudoin, J.J. (1994). Significance of Pre-Existing Cracks on Nucleation of Secondary Ettringite in Steam Cured Cement Paste. Cement and Concrete Research Vol. 24, pp 1015-1024.

Geomaterials Research Services Ltd. (1993). Report on the Petrographic Examination of Eighteen Rock Samples from Lamma Quarry with Respect to Their Potential for Alkali Aggregate Reaction by W.J. French. A report prepared for Taywood Engineering Limited.

Grattan-Bellow, P.E. & Mitchell, L. (2002). Preventing Concrete Deterioration Due to Alkali-Aggregate Reaction. Construction Technology Update No. 52. Institute for Research In Construction. National Research Council of Canada.

Heinz, D. & Ludwig, U. (1986). Mechanism of Subsequent Ettringite Formation in Mortars and Concretes after Heat Treatment. Proceedings of the 8th International Congress on the Chemistry of Cement, Rio De Janeiro, pp 189-194.

Johansen, V., Thaulow, N. & Skalny, J. (1993). Simultaneous Presence of Alkali-Silica Gel and Ettringite in Concrete. Advances in Cement Research, Vol. 5, pp 23-29.

Natesaiyer, K.C. & Hover, K.C. (1988). In Situ Identification of ASR Products in Concrete. Cement and Concrete Research, Vol. 18, pp 455-63.

Odler, I. & Chen, Y. (1995). Effect of Cement Composition on the Expansion of Heat-cured Cement Pastes. Cement and Concrete Research Vol. 25, No. 4, pp 853-62.

RILEM (2002). RILEM AAR-1: Petrographic Method - Final Draft. Internal Report RILEM/TC-ARP/02/09, 45 p.

Sewell, R.J. & Campbell, S.D.G. (2001). Petrographic Examination of Concrete Samples. GEO Report No. 119, Geotechnical Engineering Office, Civil Engineering Department, The Government of the Hong Kong Special Administrative Region, 63 p.

Shimada, Y., Johansen, V.C., Miller, F.M. & Mason, T.O. (2005). Chemical Path of Ettringite Formation in Heat-Cured Mortar and its Relationship to Expansion: A Literature Review. RD136, Portland Cement Association, Skokie, Illnois, USA. 51 p.

Skalny, J., Johansen, V., Thaulow, N. & Palomo, A. (1996). DEF as a Form of Sulfate Attack" Materiales de Construcción, Vol. 46, pp 5-29.

St John, D.A., Poole, A.B. & Sims, I. (1998). Concrete Petrography. A Handbook of Investigative Techniques. John Wiley & Sons, Inc., New York. 474 p.

Stark, D., Bollmann, K. & Seyfarth, K. (1992). Investigation into Delayed Ettringite Formation in Concrete. 9th International Conference on the Chemistry of Cement, New Delhi, pp 248-354.

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Table 1 - General Arrangement of Seawall Blocks at Tsang Tsui Ash Lagoons

Block					5					10
1-10	SM	SM	5	SM	6	SM	SM	9B	SM	SM
11-20	SM	SM	3	7	SM	4	SM	2	SM	1
21-30	SM	SM	SM	SM	SM	SM	SM	SM	SM	SM
31-40	SM	SM	SM	SM	SM	SM	SM	SM	SM	SM
41-50	SM	SM	SM	SM	SM	SM	SM	SM	SM	SM
51-60	SM	SM	SM	SM	SM	SM	SM	SM	SM	SM
61-70	SM	SM	SM	SM	SM	SM	SM	SM	SM	SM
71-80	SM	SM	SM	SM	SM	SM	SM	SM	SM	SM
81-90	SM	SM	SM	SM	SM	SM	SM	SM	SM	SM
91-100	SM	SM	SM	SM	SM	SM	SM	SM	SM	SM
101-110	SM	SM	SM	SM	SM	SM	SM	SM	SM	SM
111-120	SM	SM	SM	SM	SM	SM	SM	SM	SM	SM
121-130	SM	SM	SM	SM	SM	SM	SM	SM	SM	SM
131-140	SM	SM	SM	SM	10	SM	SM	SM	12	SM
141-150	SM	SM	SM	9A	SM	11	SM	SM	SM	SM
151-160	SM	SM	SM	SM	SM	SM	SM	SM	SM	SM
161-170	SM	SM	SM	SM	SM	17	25	SM	27	SM
171-180	30	SM	SM	SM	28	SM	SM	SM	SM	SM
181-190	34	22	35	23	36	24	SM	SM	SM	SM
191-200	SM	SM	SM	SM	SM	SM	SM	SM	SM	SM
200-207	SM	SM	SM	SM	SM	SM	SM			

Control Block
SM = Standard Mix*

Monitored Block

*Standard Mix designed as a Grade 30 concrete made from 75% OPC and 25% PFA using 20 mm and 10 mm, aggregate and fine crushed granite rock supplied by Lamma Rock Products Ltd.

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Table 2 - Design Mix, Casting, and Curing Data for Monitored Seawall Blocks Compiled from CLP (1990a,b,c)

Corehole	WW	[1]Mix	SO_3 wt%	Al_2O_3 wt%	[2]Mol. Ratio	[3]T°C (A)	[4]T°C (FC)	Max °C	Rise °C	[5]W/C	[6]Mould	[7]T/C	Shrinkage Cracks Observed
CH1	35	A/40/0	2.3	5.9	0.50	26.5	30	90.9	60.9	0.47	T	Y	
CH2	35	A/40/0	2.3	5.9	0.50	26.5	30	90.9	60.9	0.47	T	Y	
CH3	9A	F/30/0	1.5	4.4	0.43	29	31	76.2	45.2	0.55	S	Y	A = 1.3 mm Wide, 800 mm Long, B = 0.8 mm wide, 140 mm Long, C = 0.6 mm Wide, 200 mm Long
CH4	9A	F/30/0	1.5	4.4	0.43	29	31	76.2	45.2	0.55	S	Y	
CH5	34	A/20/0	2.3	5.9	0.50	26	28.7	74.1	45.4	0.69	T	Y	
CH6	28	AB/30/25	2.6	6.0	0.55	26.5	29.7	81.3	51.6	0.53	T	Y	A = 0.5 mm Wide, 380 mm Long, B = 0.5 mm Wide, 130 mm Long
CH7	5	A/30/0	2.3	5.9	0.50	24.6	29.8	83.5	30.3	0.57	S	Y	
CH8	9B	F/30/0	1.5	4.4	0.43	29	31	77.7	47.7	0.55	T	Y	
CH9	3	A/30/0	2.3	5.9	0.50	28.9	32			0.57	S	N	

[1]Mix Design Designation after CLP (1990a)
A = OPC from China Cement Company (Tricalcium Aluminate (C_3A) = 10.1 - 11.5%)
B = PFA from China Light & Power Company (CLP) Ltd.
F = Sulphate-resisting cement from Taiwan Cement Co. Ltd. (Tricalcium Aluminate (C_3A) = 1%)
Example: Standard Mix AB/30/25 designed as a Grade 30 concrete made from 75% OPC and 25% PFA
[2]Mol. Ratio = Molar Ratio SO_3/Al_2O_3,
[3] T°C (A) = Ambient air temperature at the time of casting,
[4]T°C (FC) = Fresh concrete temperature at time of casting,
[5]W/C = Water/Cement Ratio,
[6]T = Timber, S = Steel,
[7]T/C = Thermocouple,

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Table 3 - Design Mix Proportions for Monitored Seawall Blocks Compiled from CLP (1990a,b,c)

Corehole	WW	[1]Mix	Design Strength N/mm²	Tot Cement. Mat.	Cement	PFA	% of PFA	20 mm	10 mm	Fines	% of Fines	Tot. Agg.	Water	Hycol	Ratios		Dens.	Vol.
															A/C	W/C		
CH1	35	A/40/0	54	425	425	-	-	815	350	545	31.9	1710	200	0.85	4.02	0.47	2335	0.998
CH2	35	A/40/0	54	425	425	-	-	815	350	545	31.9	1710	200	0.85	4.02	0.47	2335	0.998
CH3	9A	F/30/0	44	345	345	-	-	800	340	660	36.7	1800	190	0.69	5.22	0.55	2335	0.997
CH4	9A	F/30/0	44	345	345	-	-	800	340	660	36.7	1800	190	0.69	5.22	0.55	2335	0.997
CH5	34	A/20/0	34	290	290	-	-	765	325	730	40.1	1820	200	0.58	6.28	0.69	2310	0.997
CH6	28	AB/30/25	44	380	285	95	25	835	360	530	30.8	1725	200	0.76	4.54	0.53	2305	0.998
CH7	5	A/30/0	44	350	350	-	-	790	340	645	36.3	1775	200	0.70	5.07	0.57	2325	0.998
CH8	9B	F/30/0	44	345	345	-	-	800	340	660	36.7	1800	190	0.69	5.22	0.55	2335	0.997
CH9	3	A/30/0	44	350	350	-	-	790	340	645	36.3	1775	200	0.70	5.07	0.57	2325	0.998

[1]Mix Design Designation after CLP (1990a)

Table 4 - Details of Petrographic Specimens from Corehole Samples in Seawall Blocks at Tsang Tsui Ash Lagoons

Corehole	WW	Mix	Depth	Position	Specimens For Petrographic Examination
CH1	35	A/40/0	2070 mm	Vertical	0-60†, 75-135†*, 180-240†*, 1000-1060† & 1930-1990† mm
				Horiz.	20-30†, 65-75†, 135-145§†*, 240-250†*, 1060-1070†* & 1990-2000†* mm
CH2	35	A/40/0	2040 mm	Vertical	0-60†, 75-135†* & 180-240†* mm (Duplicate)
				Horiz.	20-30†, 135-145†* & 240-250†* mm
CH3	9A	F/30/0	2060 mm	Vertical	0-60†, 1000-1060†* & 1960-2020† mm
				Horiz.	20-30†, 65-75†*, 1060-1070†* & 2020-2030§†* mm
CH4	9A	F/30/0	2080 mm	Vertical	0-60† & 75-135† mm (Duplicate)
				Horiz.	20-30† & 65-75† mm
CH5	34	A/20/0	1270 mm	Vertical	0-60†, 75-135†, 180-240† & 1000-1060† mm
				Horiz.	20-30, 65-75†, 135-145†, 240-250†* & 1060-1080§†* mm
CH6	28	AB/30/25	1300 mm	Vertical	0-60, 75-135 & 180-240 mm (Control)
				Horiz.	20-30, 65-75, 135-145 & 240-250§ mm (Control)
CH7	5	A/30/0	1260 mm	Vertical	0-60†, 75-135†, 180-240†* & 950-1010†* mm
				Horiz.	20-30†, 65-75†, 135-145†*, 240-250§†* & 1010-1020†* mm
CH8	9B	F/30/0	1380 mm	Vertical	0-60†, 75-135†* & 240-300§†* mm
				Horiz.	20-30†, 65-75† & 300-310† mm
CH9	3	A/30/0	1300 mm	Vertical	0-60†, 75-135†* & 180-240† mm
				Horiz.	20-30†, 65-75† & 170-180§†* mm

Legend:

§ Polished slab specimens tested with uranyl acetate solution
† Thin sections which reveal the presence of ettringite
* Thin sections which reveal the presence of alkali-silica gel

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Table 5 - Summary of Observations from the Uranyl-Acetate Test

Corehole no	Seawall Block no	Cement Type	Greenish-yellow Fluorescence
CH1	WW35	OPC	Bright
CH2	WW35	OPC	Bright
CH3	WW9A	SRC	Moderate
CH4	WW9A	SRC	Moderate
CH5	WW34	OPC	Bright
CH6	WW28	OPC/PFA	Weak
CH7	WW5	OPC	Bright
CH8	WW9B	SRC	Moderate
CH9	WW3	OPC	Moderate

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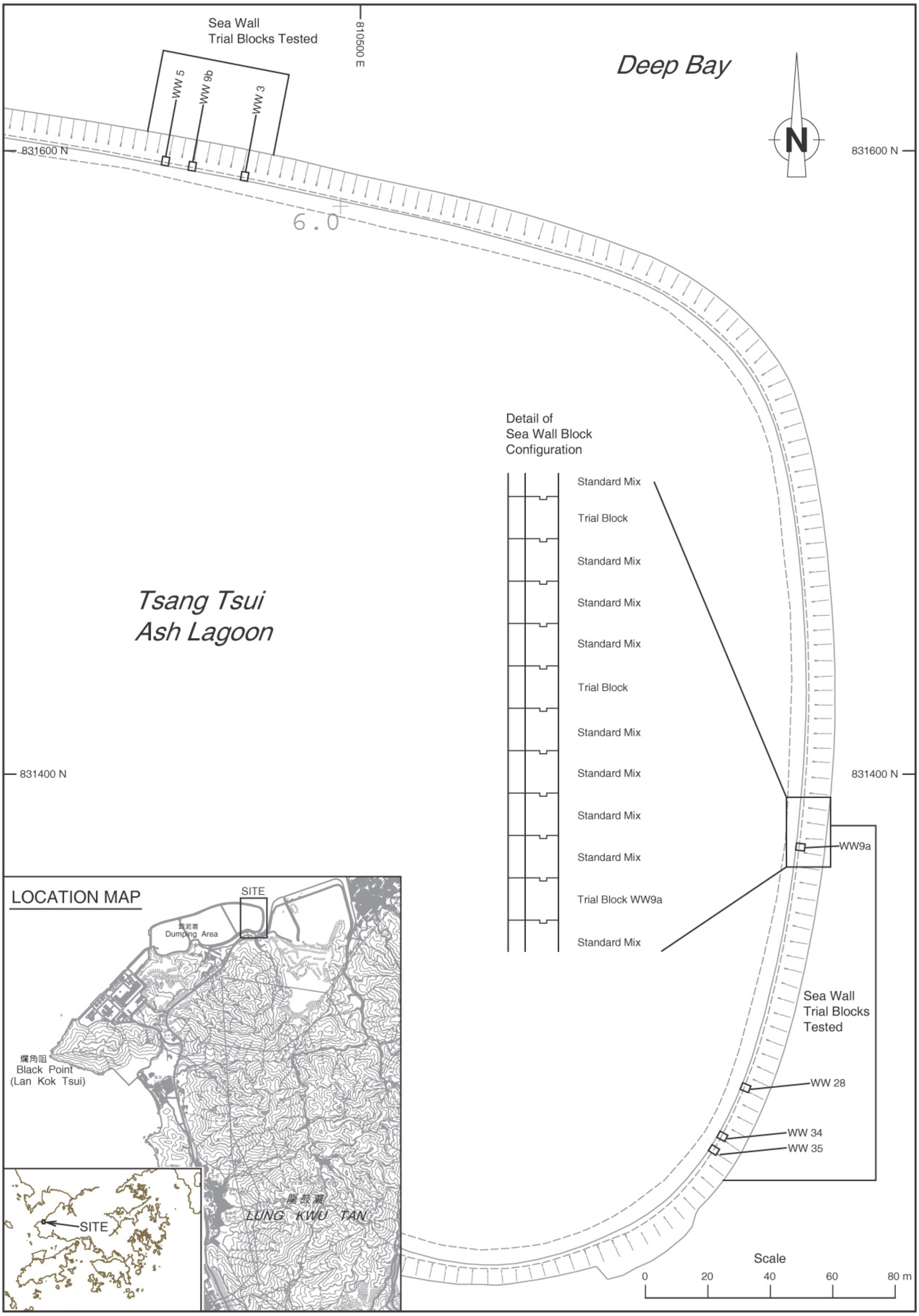

Figure 1 - General Location of Tsang Tsui Ash Lagoons and Layout of Seawall Blocks

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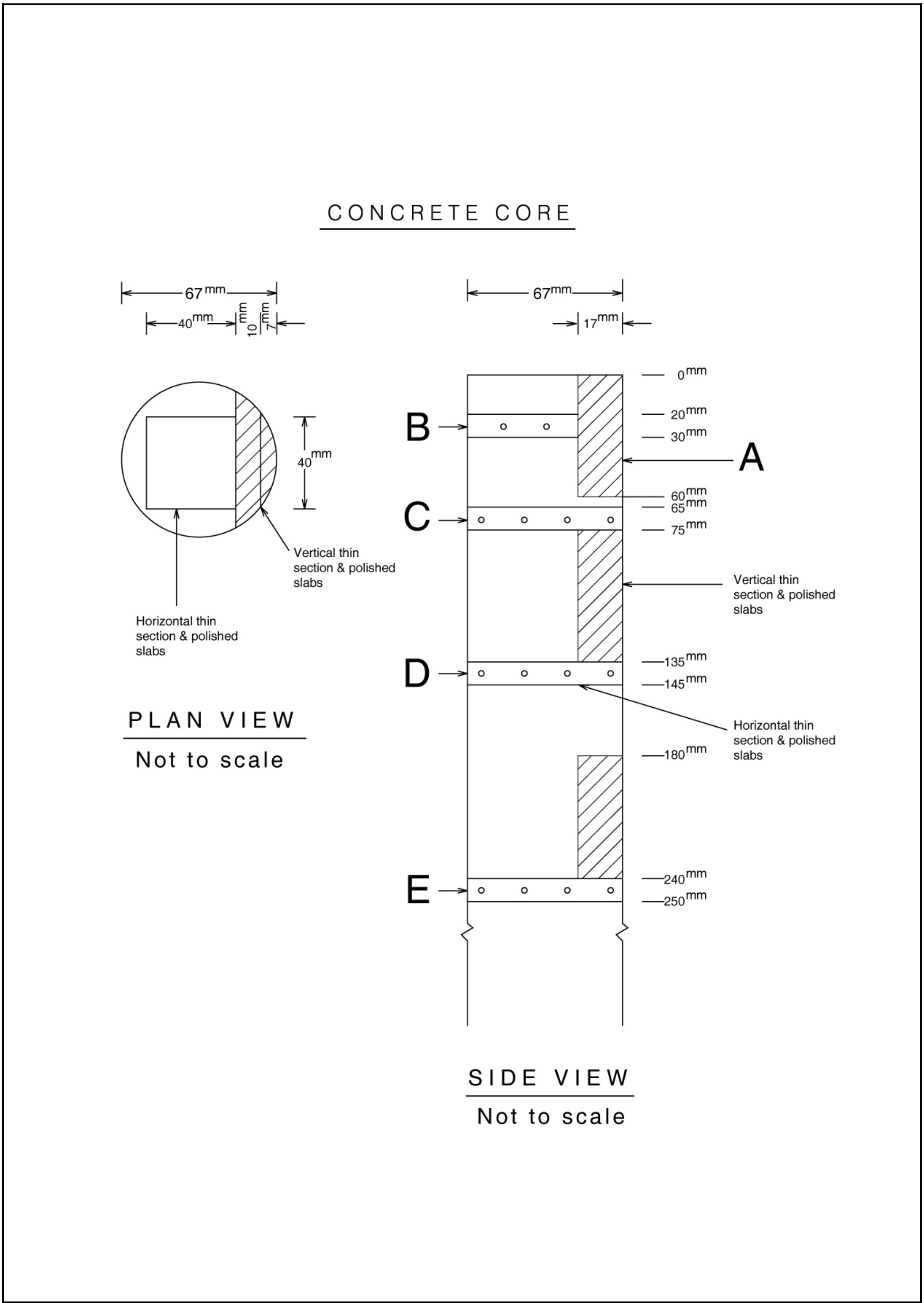

Figure 2 - General Orientation of Concrete Thin Section and Polished Slab Specimens Taken from Corehole Samples

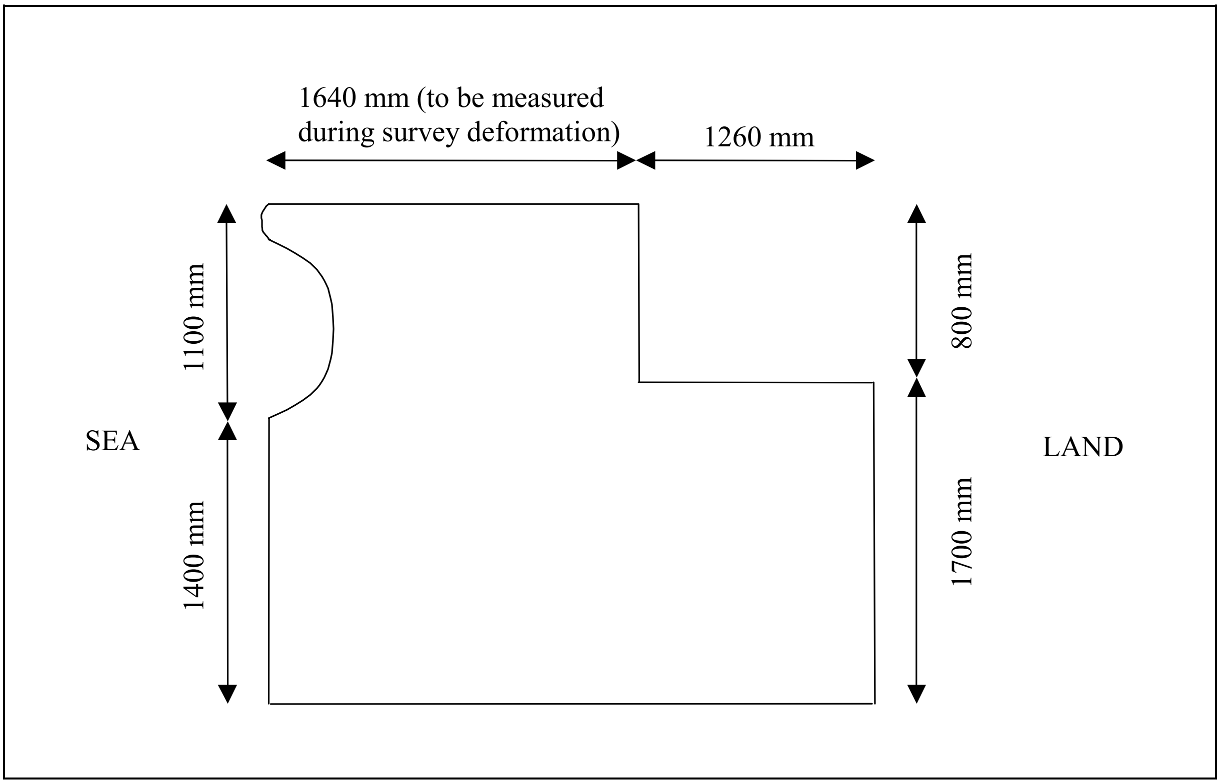

Figure 3 - Typical Section of a Seawall Block (provided by Consultants)

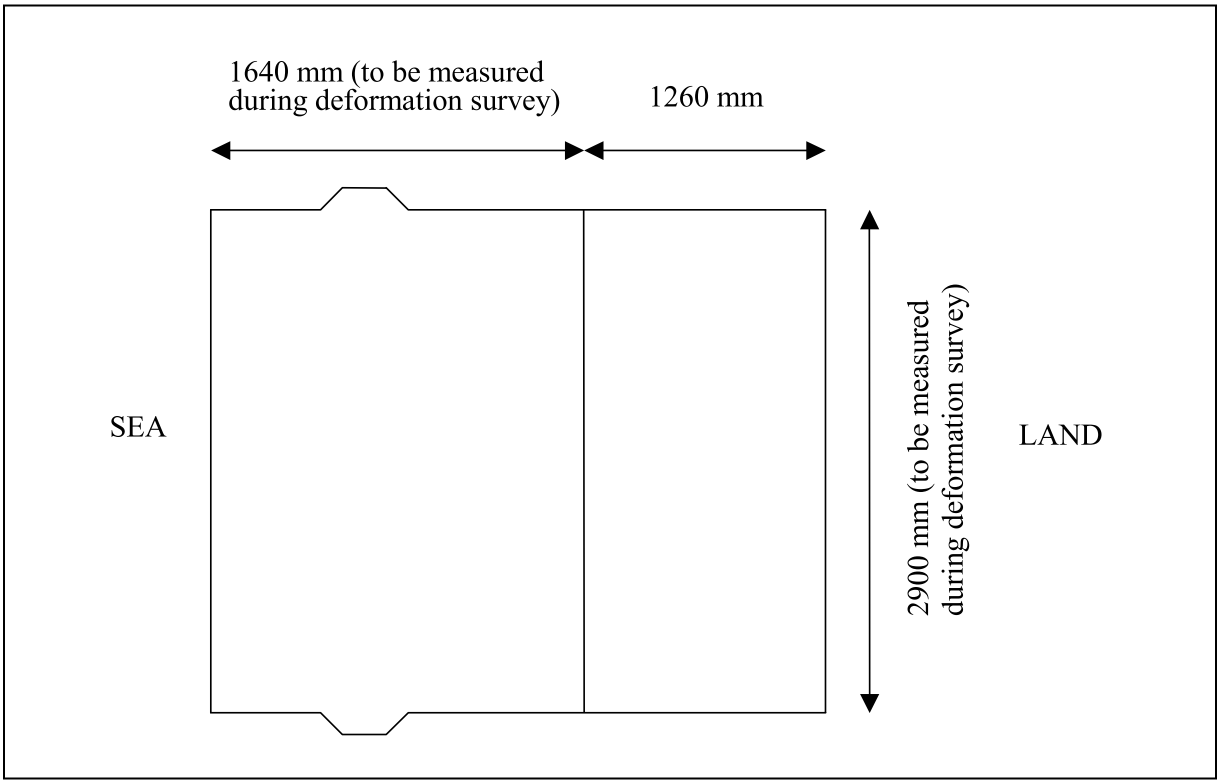

Figure 4 - Plan View of a Typical Seawall Block (provided by Consultants)

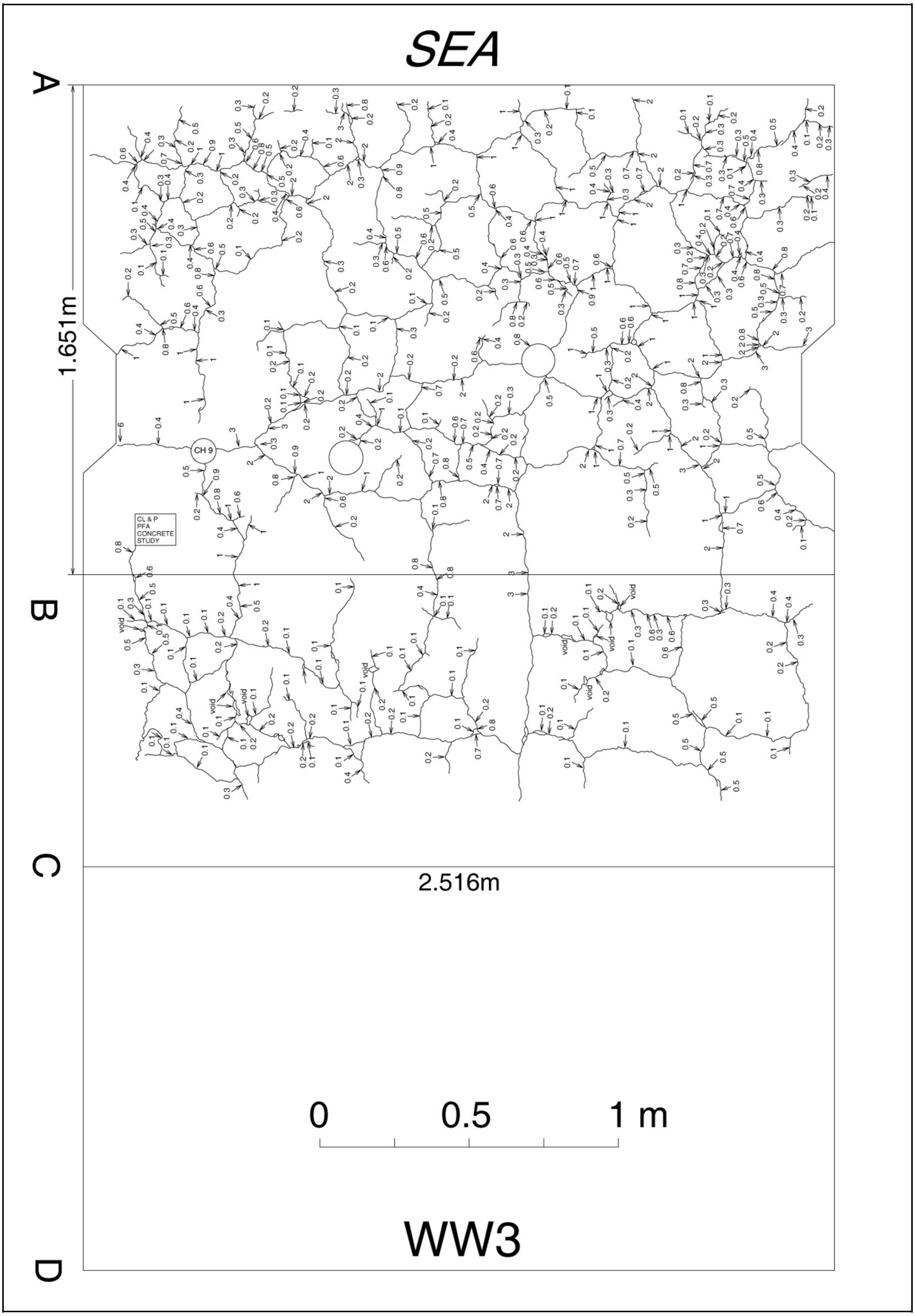

Figure 5 - Surface Crack Patterns and Width Measurements for Seawall Block WW3

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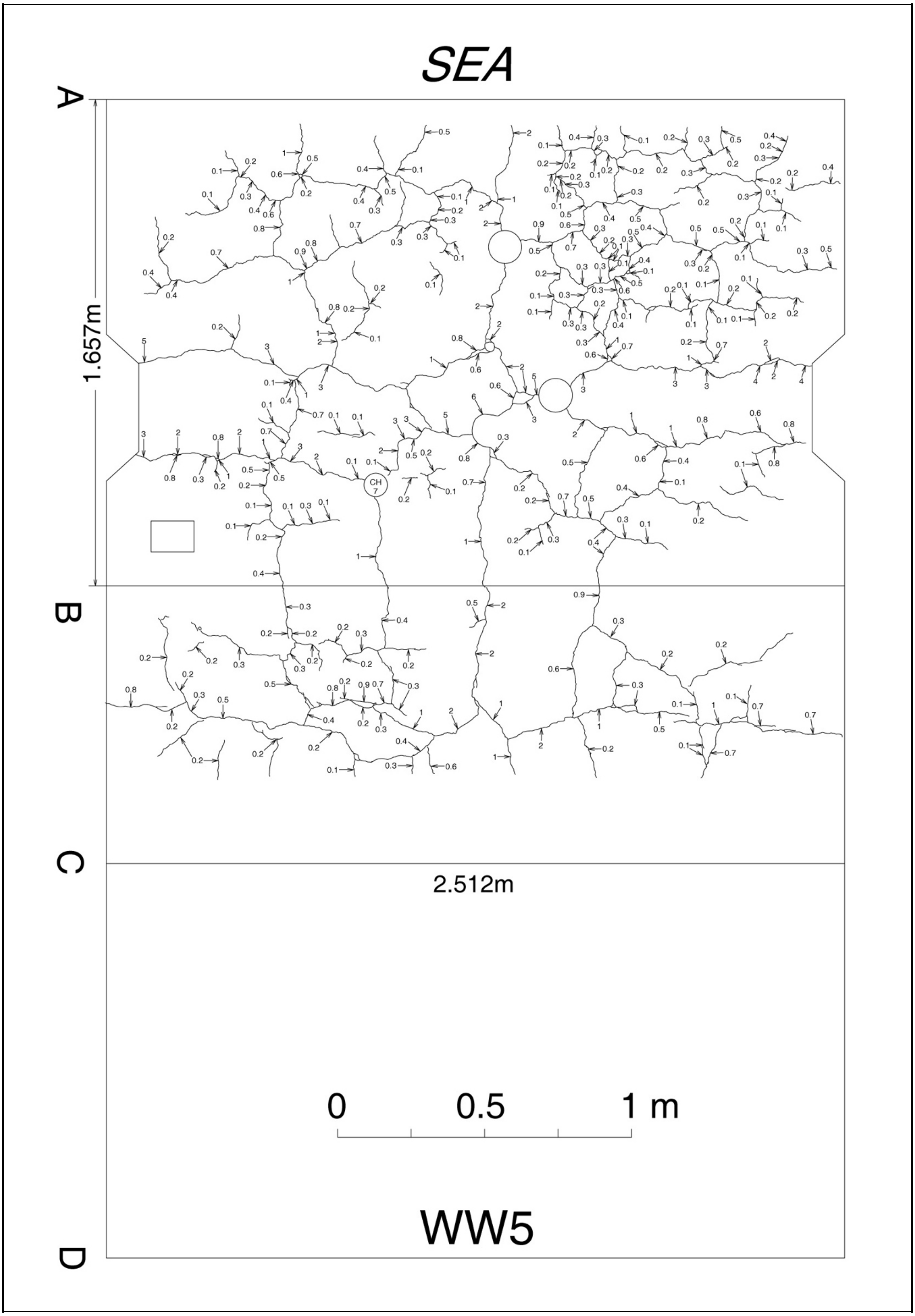

Figure 6 - Surface Crack Patterns and Width Measurements for Seawall Block WW5

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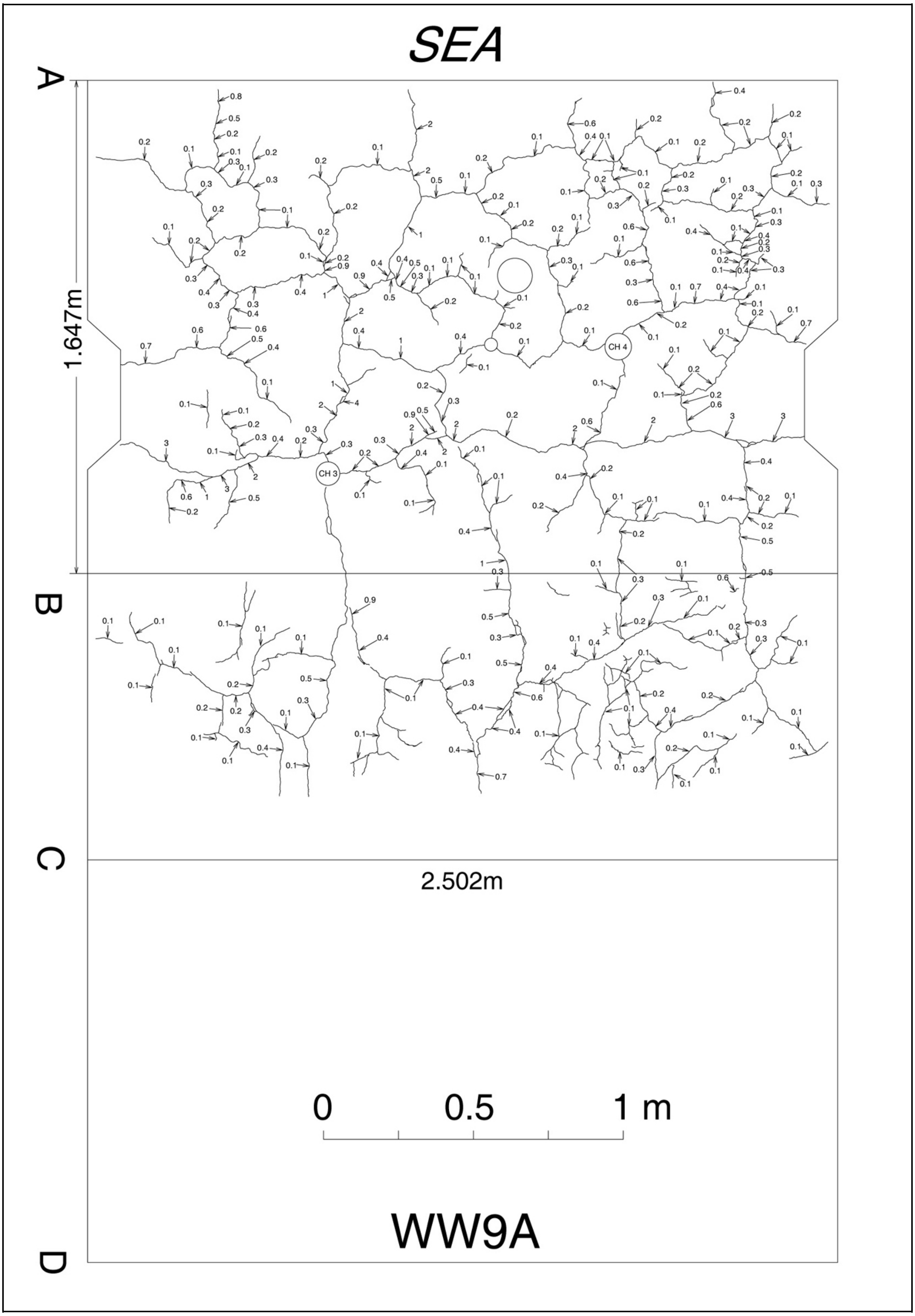

Figure 7 - Surface Crack Patterns and Width Measurements for Seawall Block WW9A

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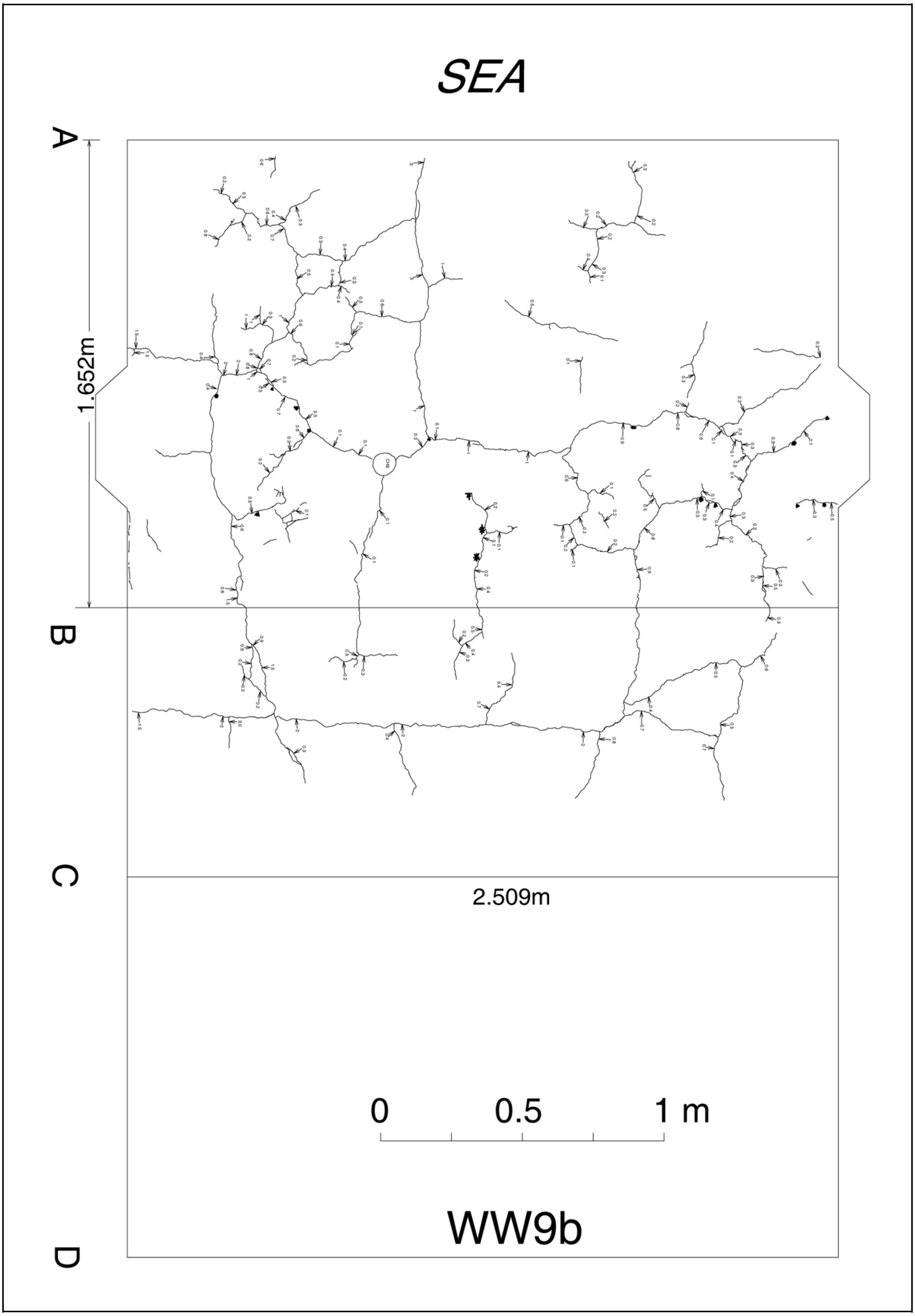

Figure 8 - Surface Crack Patterns and Width Measurements for Seawall Block WW9B

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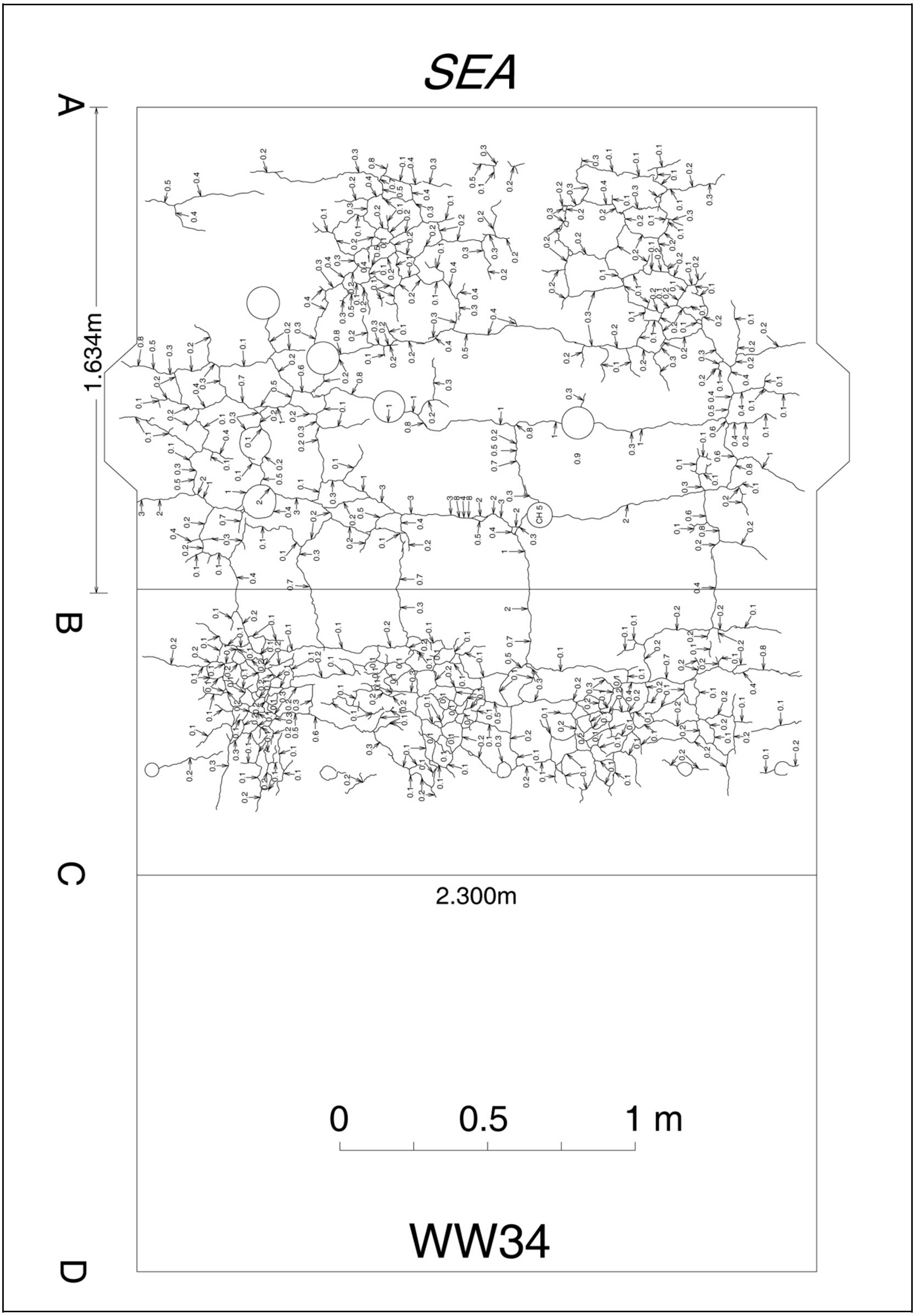

Figure 9 - Surface Crack Patterns and Width Measurements for Seawall Block WW34

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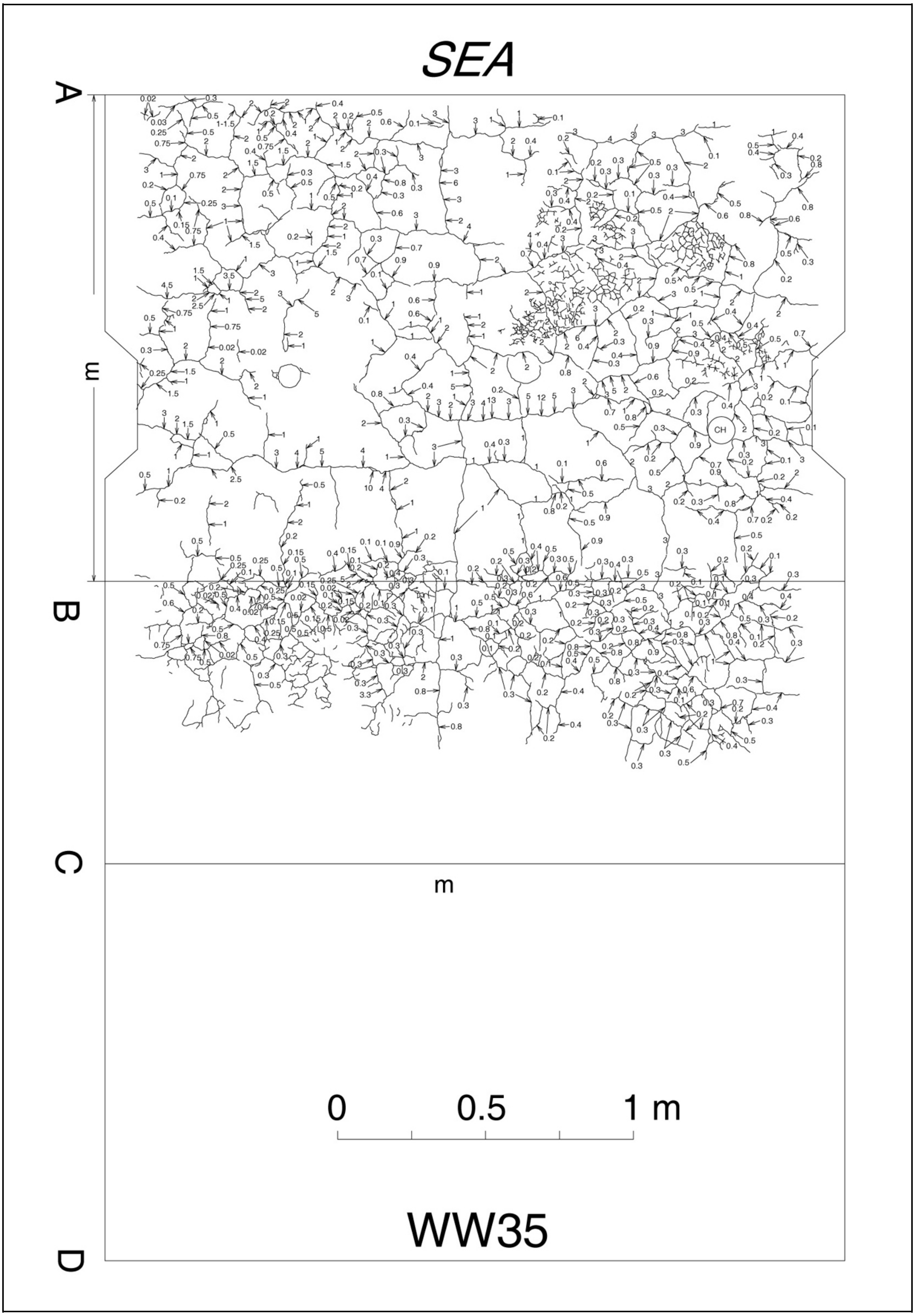

Figure 10 - Surface Crack Patterns and Width Measurements for Seawall Block WW35

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Plate 2 - Typical Location of Concrete Cores at Triple Junction of Major Cracks

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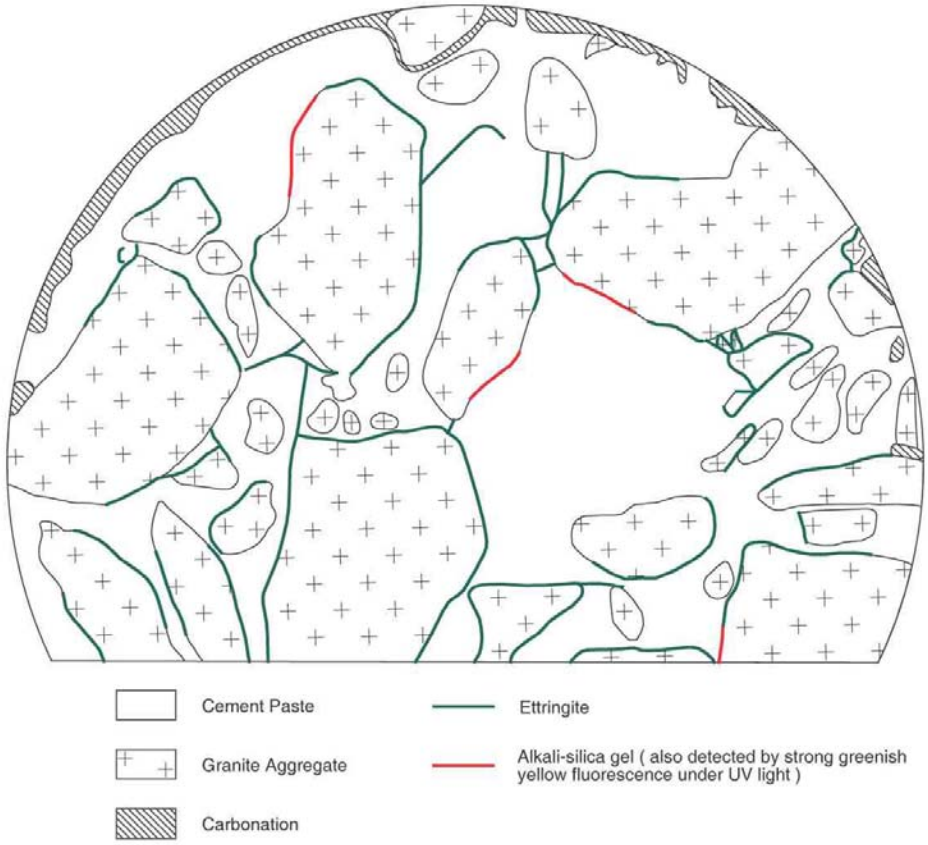

Plate 3a - Thin Section Sketch Showing Areas of Known Ettringite and Alkali-silica Gel

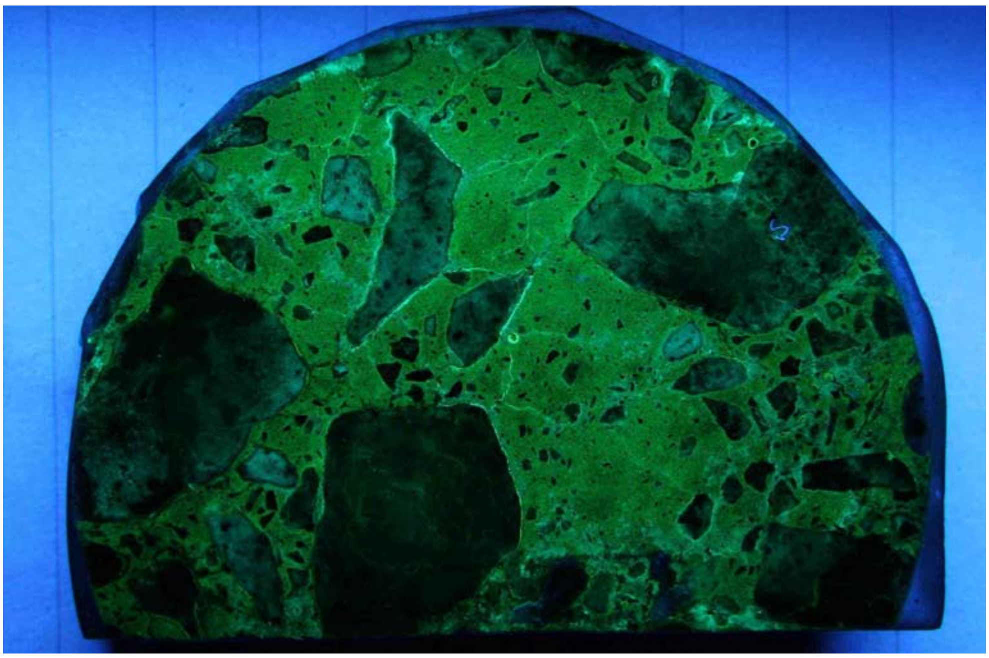

Plate 3b - Polished Slab of WW35 Treated with Uranyl Acetate Solution and Viewed under 254 nm Ultraviolet Light (P0611_027D, A1F, 135-145 mm horizontal)

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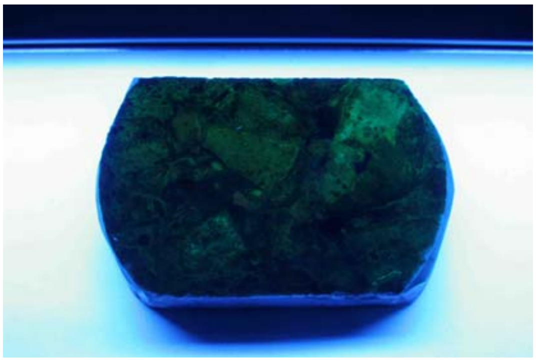

Plate 4a - Polished Slab of WW28 Treated with Uranyl Acetate Solution and Viewed under 254 nm Ultraviolet Light (IMG_2269, B2B, 240-250 mm horizontal)

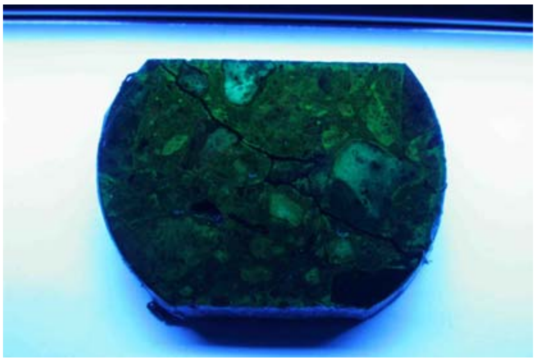

Plate 4b - Polished Slab of WW3 Treated with Uranyl Acetate Solution and Viewed under 254 nm Ultraviolet Light (IMG_2279, B8F, 170-180 mm horizontal)

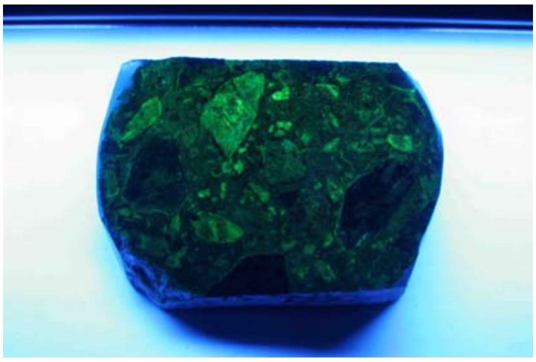

Plate 4c - Polished Slab of WW5 Treated with Uranyl Acetate Solution and Viewed under 254 nm Ultraviolet Light (IMG_2273, B4B, 240-250 mm horizontal)

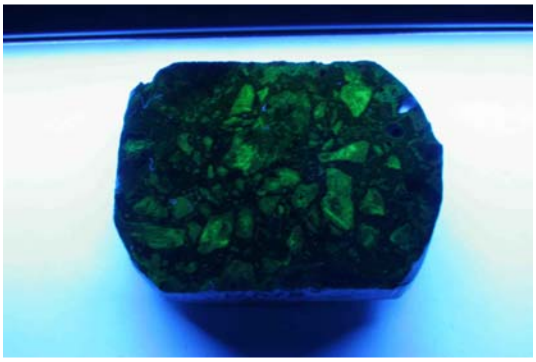

Plate 4d - Polished Slab of WW9A Treated with Uranyl Acetate Solution and Viewed under 254 nm Ultraviolet Light (IMG_2266, A7B, 2020-2030 mm horizontal)

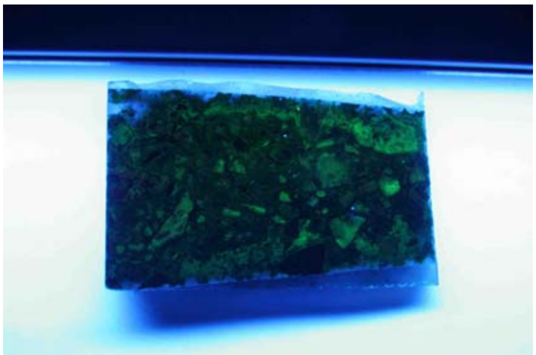

Plate 4e - Polished Slab of WW9B Treated with Uranyl Acetate Solution and Viewed under 254 nm Ultraviolet Light (IMG_2276, B7A, 240-300 mm vertical)

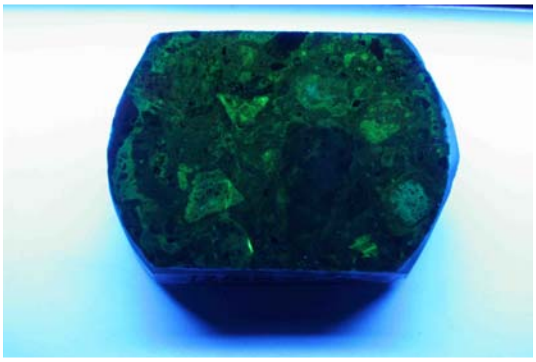

Plate 4f - Polished Slab of WW34 Treated with Uranyl Acetate Solution and Viewed under 254 nm Ultraviolet Light (IMG_2268, A0B, 1060-1080 mm horizontal)

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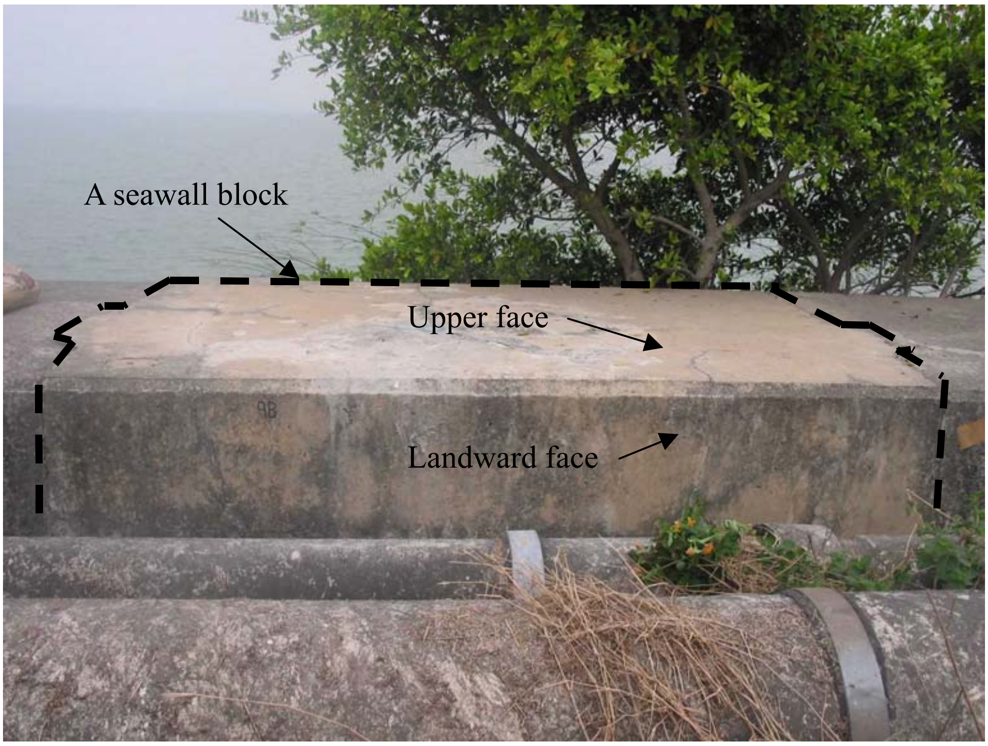

Plate 5 - Upper Face and Landward Face of a Typical Seawall Block

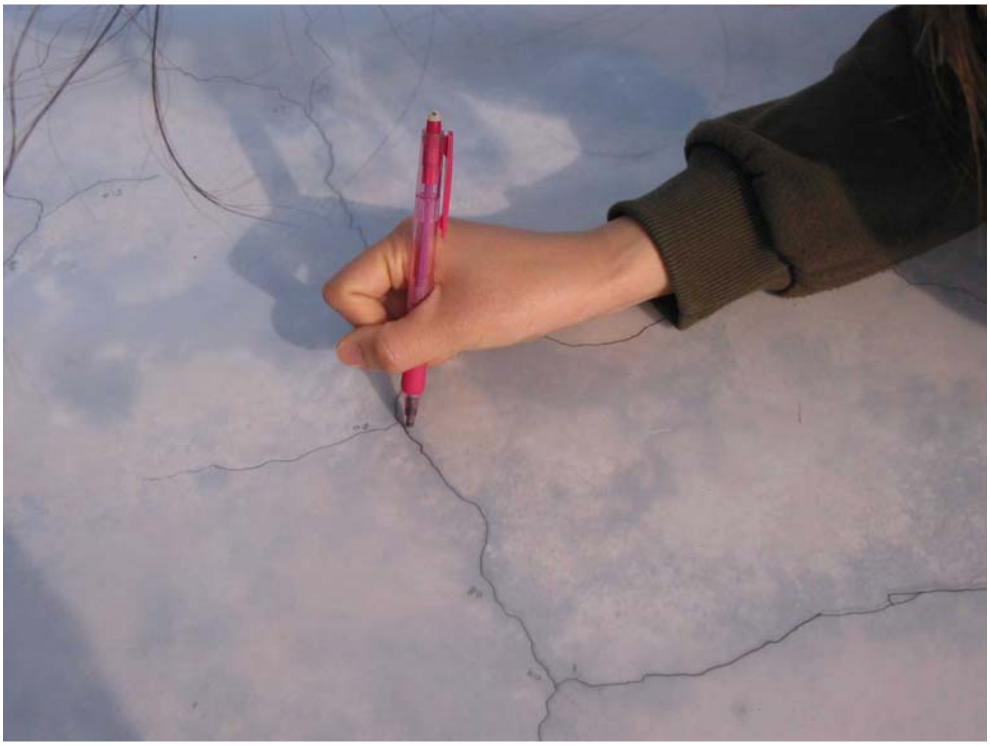

Plate 6 - Mapping of Crack Pattern on Tracing Paper

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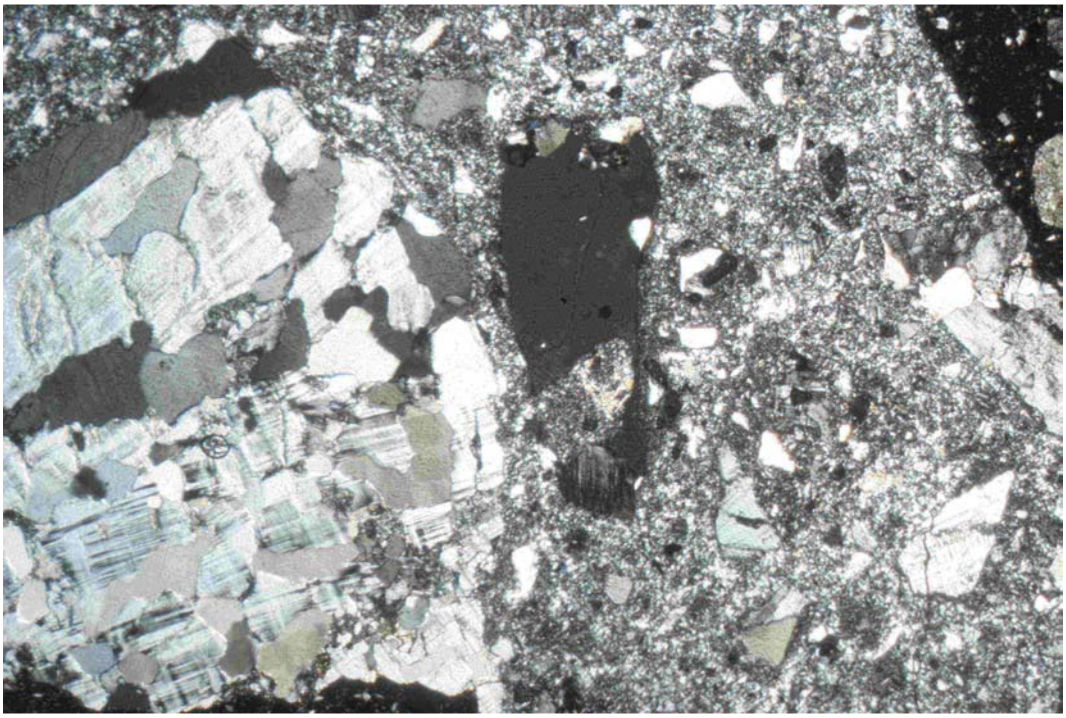

Plate 9 - Aggregate Fragment of Tuffisite (CPL, Field of View = 0.72 mm, B1B, IMG_2298, 75 - 135 mm, Vertical)

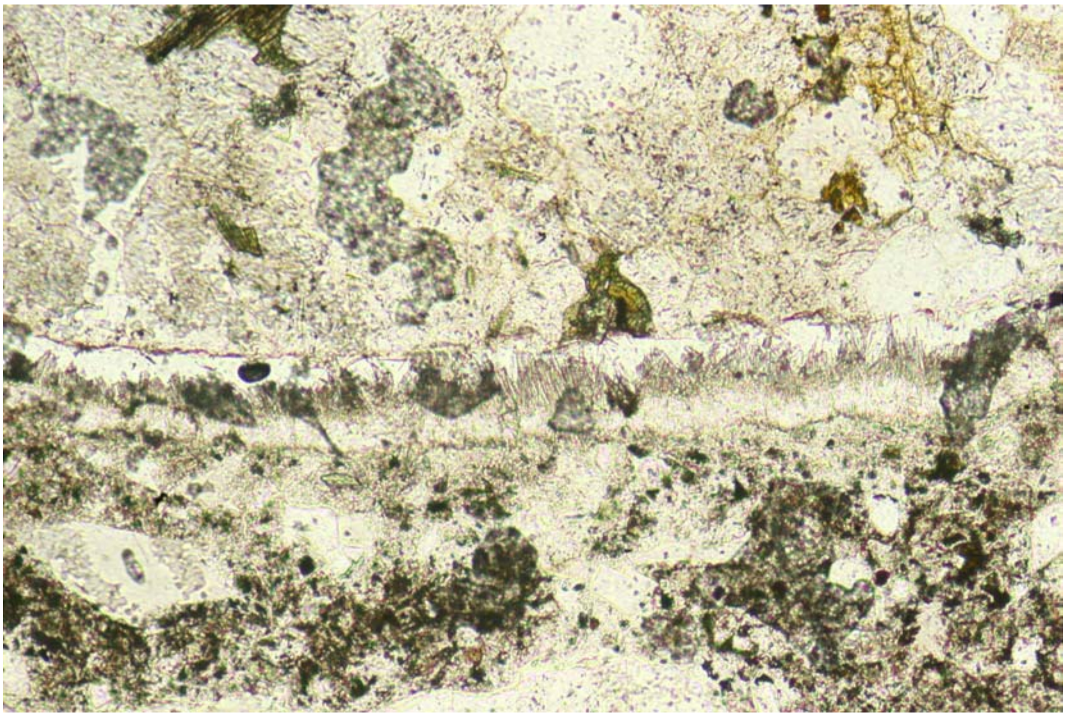

Plate 10 - Ettringite Growing from Paste into a Ring Crack Surrounding an Aggregate Fragment (PPL, Field of View = 0.72 mm, B8F, IMG_2683, 170 - 180 mm, Horizontal)

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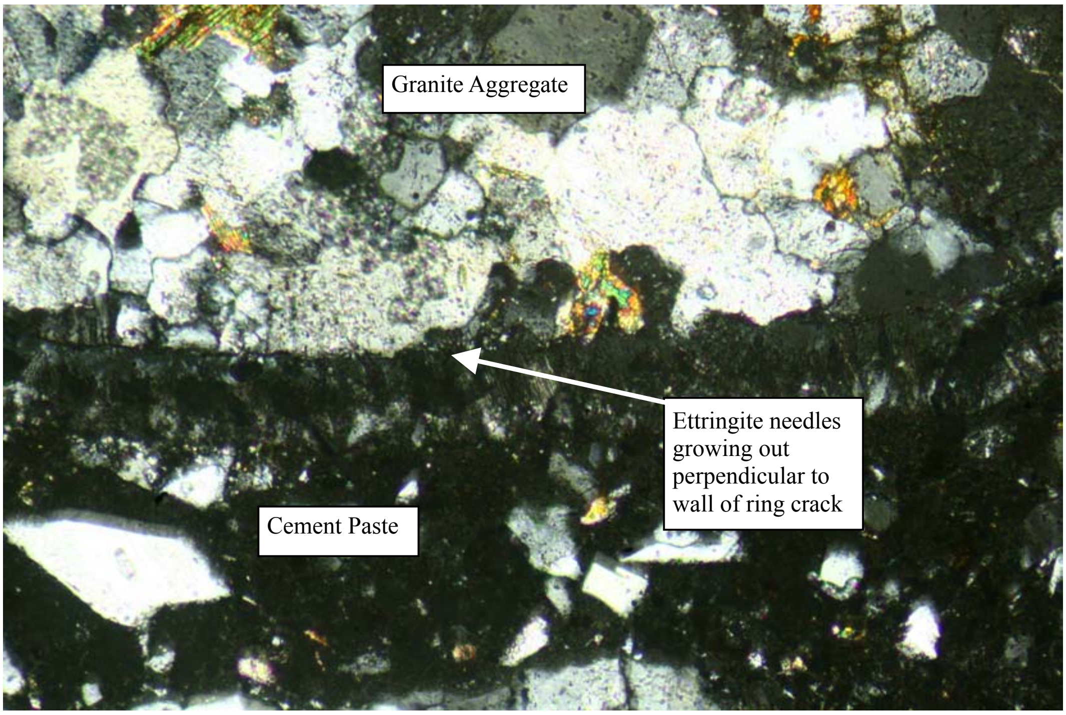

Plate 11 - Curtain-like Growth of Ettringite into Ring Crack Surrounding an Aggregate Fragment (CPL, Field of View = 0.72 mm, B8F, IMG_2685, 170 - 180 mm, Horizontal)

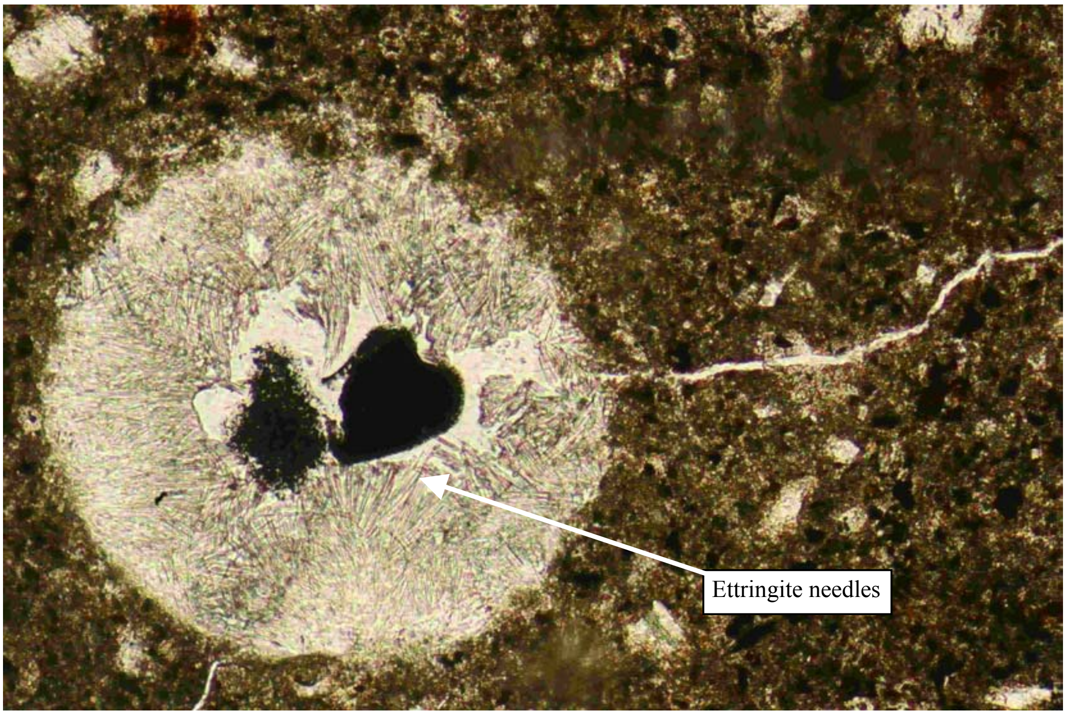

Plate 12 - Ettringite Almost Completely Filling An Air Void (Arrowed) (PPL, Field of view = 0.72 mm, P0605-009D, B3E, 135 - 145 mm, Horizontal)

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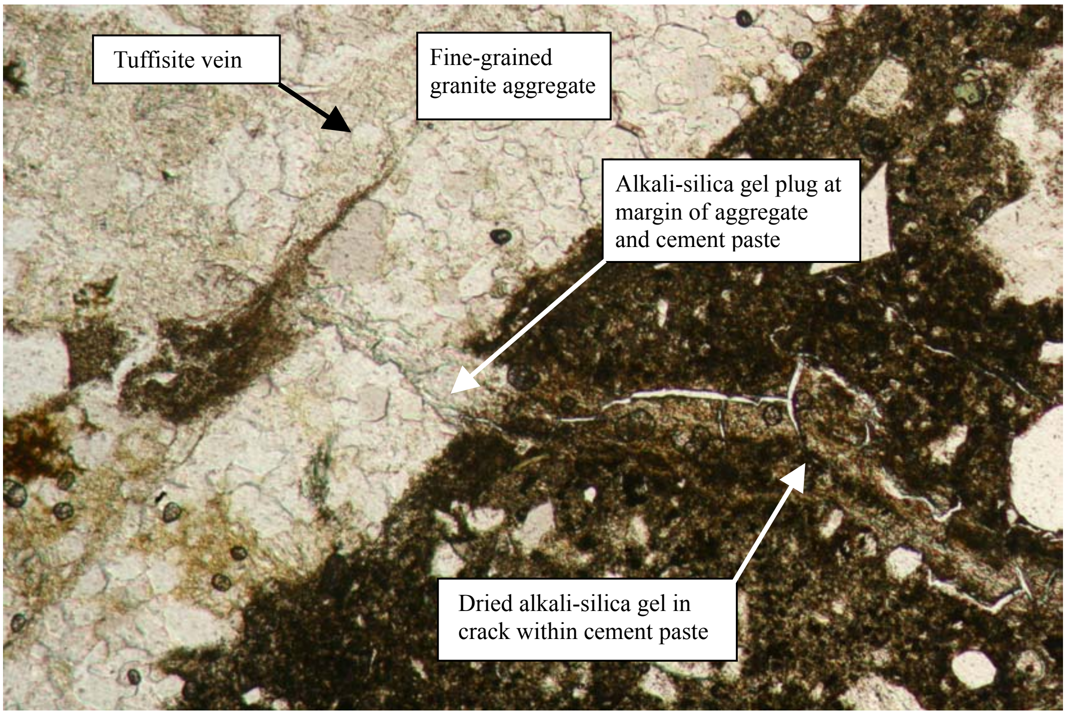

Plate 13 - Alkali-silica Gel Exuding into Cement Paste from Tuffisite Vein in Fine-grained Granite Aggregate. Note Desiccation of Gel in Crack to Produce Conchoidal Fractures (PPL, Field of view = 1.44 mm, IMG_2542, B4B, 240 - 250 mm, Horizontal)

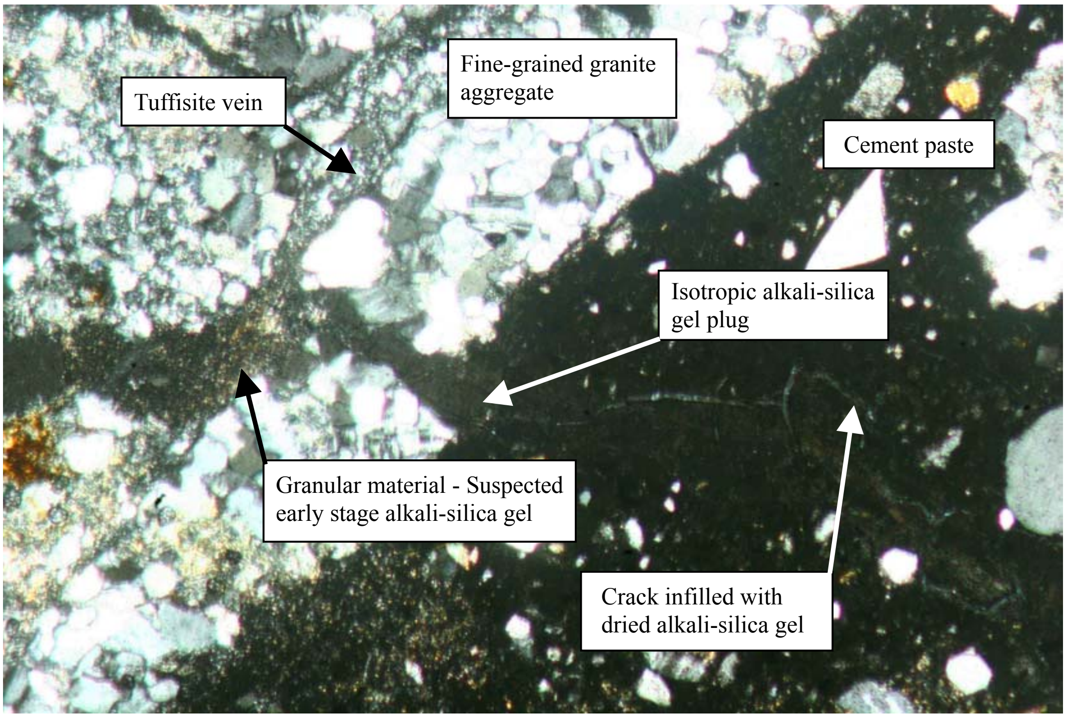

Plate 14 - Same View as Plate 13. Note Isotropic Alkali-silica Gel Exuding into Cement Paste and Partly Recrystallised Gel at Intersection of Crack and Tuffisite Vein in Granite Aggregate (CPL, Field of View = 1.44 mm, IMG_2540, B4B, 240 - 250 mm, Horizontal)

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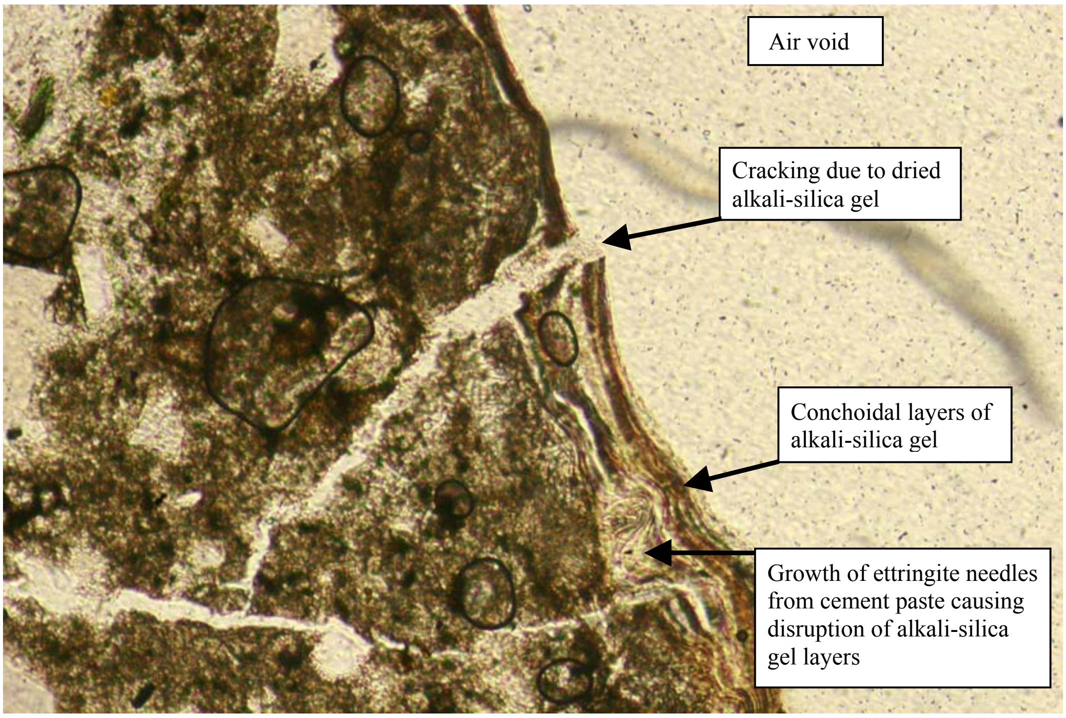

Plate 15 - Layered Alkali-silica Gel Bordering An Air Void Subsequently Disrupted by Growth of Ettringite from Cement Paste (PPL, Field of View = 0.72 mm, P0605-011D, B3E, 135 - 145 mm, Horizontal)

Plate 16 - Radiating Clusters of Acicular Ettringite Needles Growing Out from Margin of Air Void (PPL, Field of View = 1.44 mm, A3A, P0604-158D, 65 - 75 mm, Horizontal)

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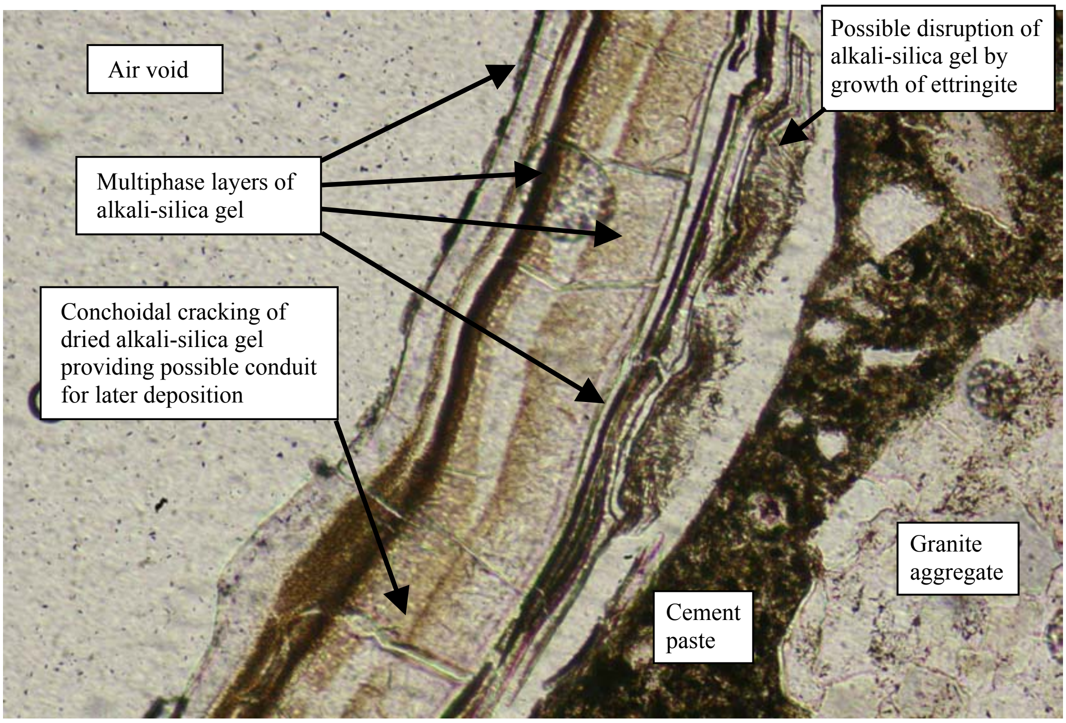

Plate 17 - Margin of Air Void Showing Multiphase Layers of Alkali-silica Gel and Possible Disruption by Growth of Ettringite from Void Walls (PPL, Field of View = 0.72 mm, IMG_2651, A7B, 2020 - 2030 mm, Horizontal)

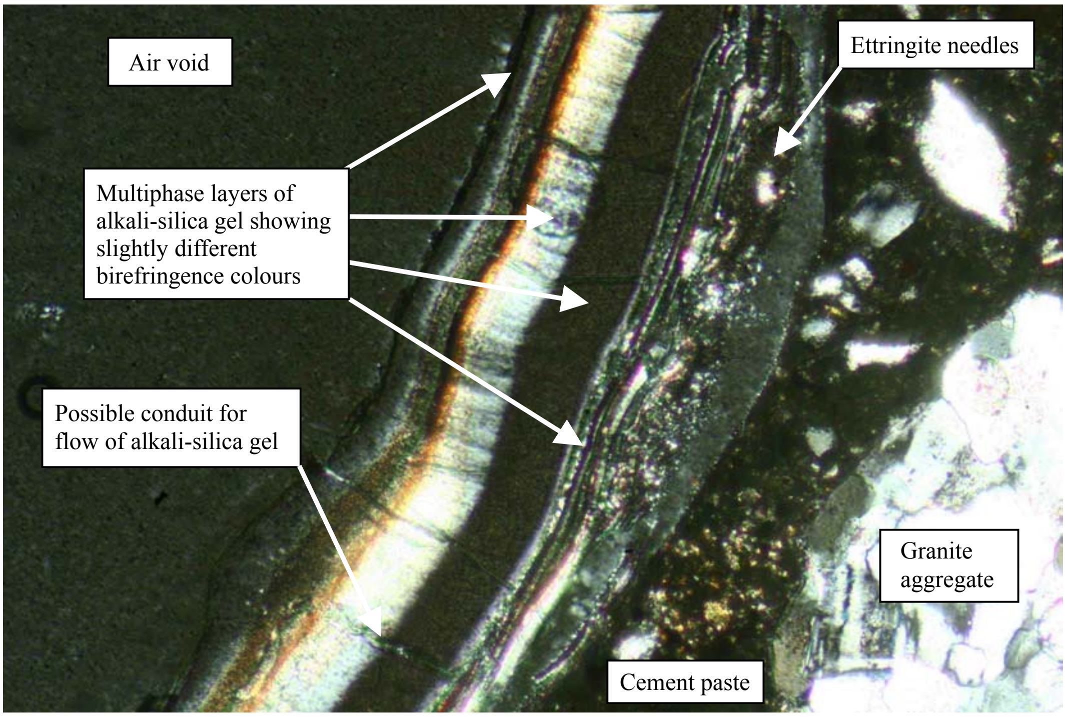

Plate 18 - Same View As above (CPL, Field of View = 0.72 mm, IMG_2653, A7B, 2020 - 2030 mm, Horizontal)

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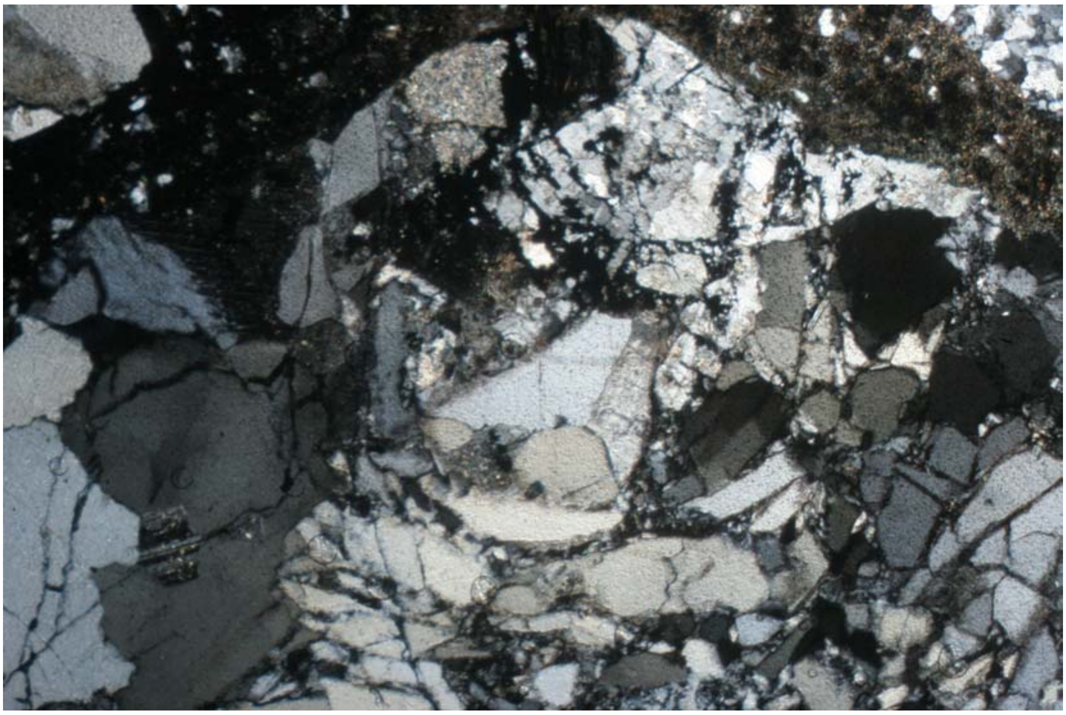

Plate 19 - Cataclasite Fracture in Fine Grained Granite Aggregate with Slightly Strained Quartz (CPL, Field of View = 2.9 mm, IMG_2328, B7A, 240 - 300 mm, Vertical)

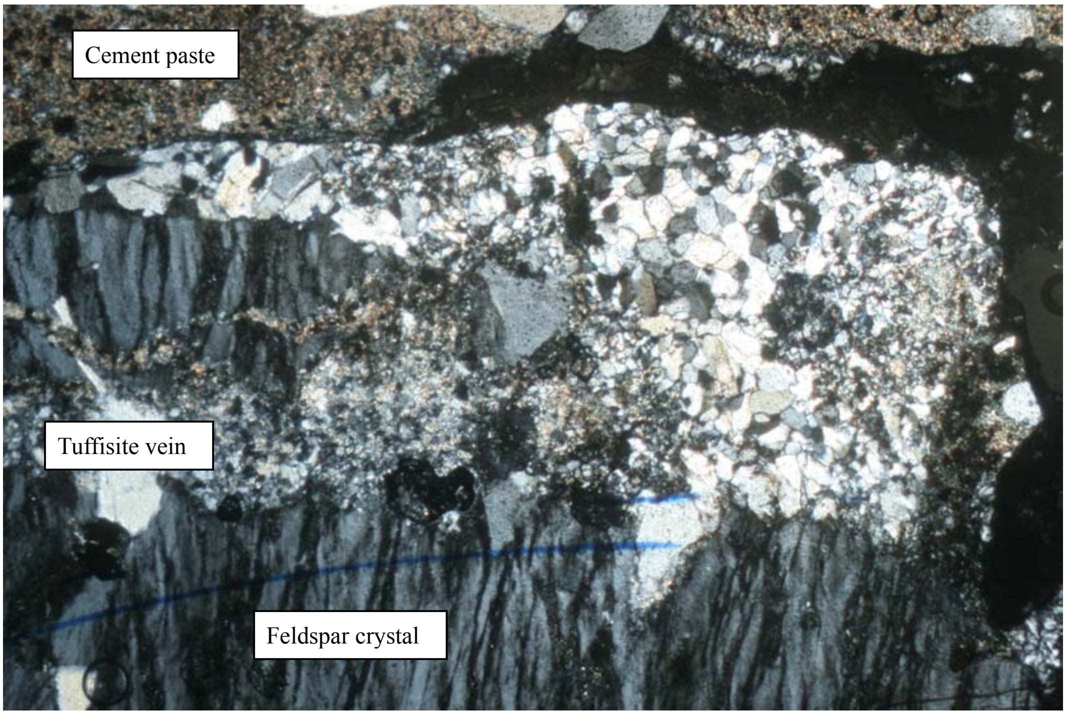

Plate 20 - Tuffisite Vein Disrupting a Feldspar Crystal within a Medium-grained Granite Aggregate Fragment (CPL, Field of View = 1.44 mm, IMG_2219, A0B, 1060 - 1080 mm, Horizontal)

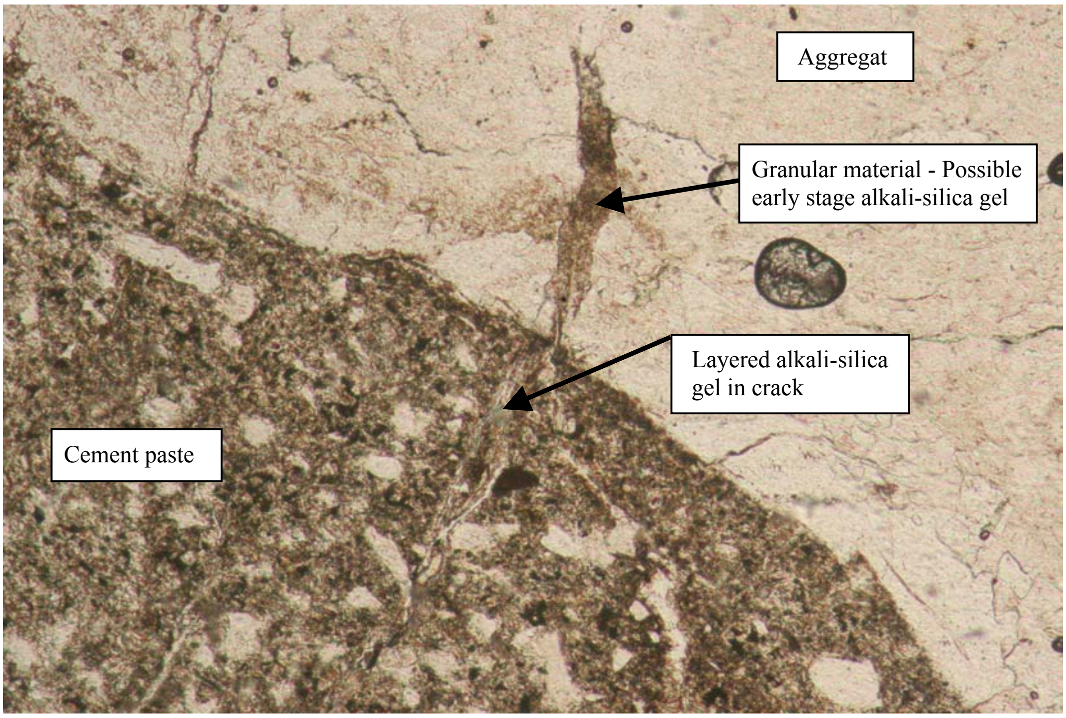

Plate 21 - Alkali-silica Gel Exuding from a Tuffisite Vein within Fine-grained Aggregate Fragment (PPL, Field of View = 1.44 mm, IMG_2253, A1F, 135 - 145 mm, Horizontal)

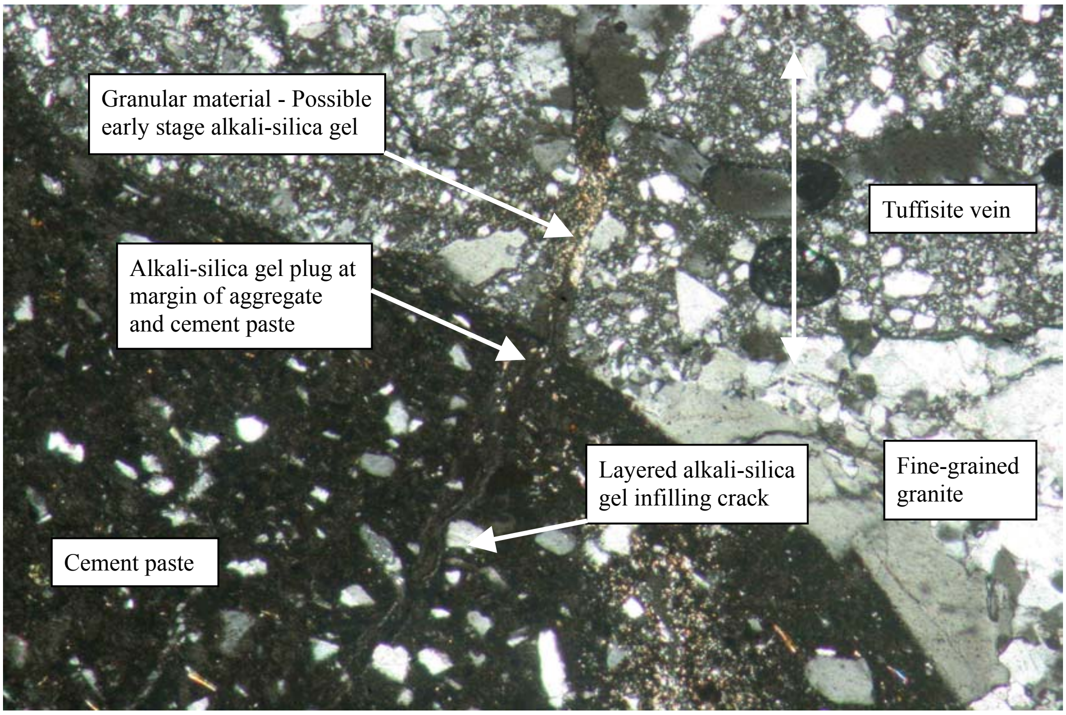

Plate 22 - Similar View As above. Note the Weakly Birefringent Material in the Crack of the Tuffisite Vein, Which is Possibly Recrystallised Alkali-silica Gel (CPL, Field of View = 1.44 mm, IMG_2256, A1F, 135 - 145 mm, Horizontal)

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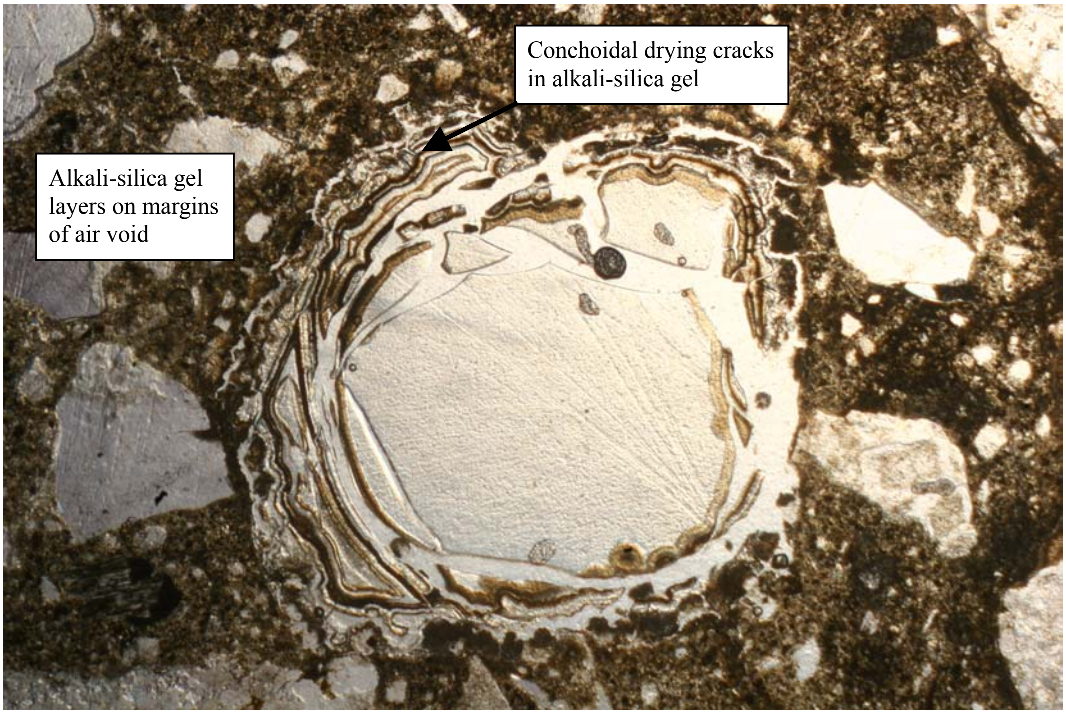

Plate 23 - Multiple Layers of Alkali-silica Gel Infilling an Air Void (PPL, Field of View = 2.9 mm, IMG_2742, A3B, 1990-2000 mm, Horizontal)

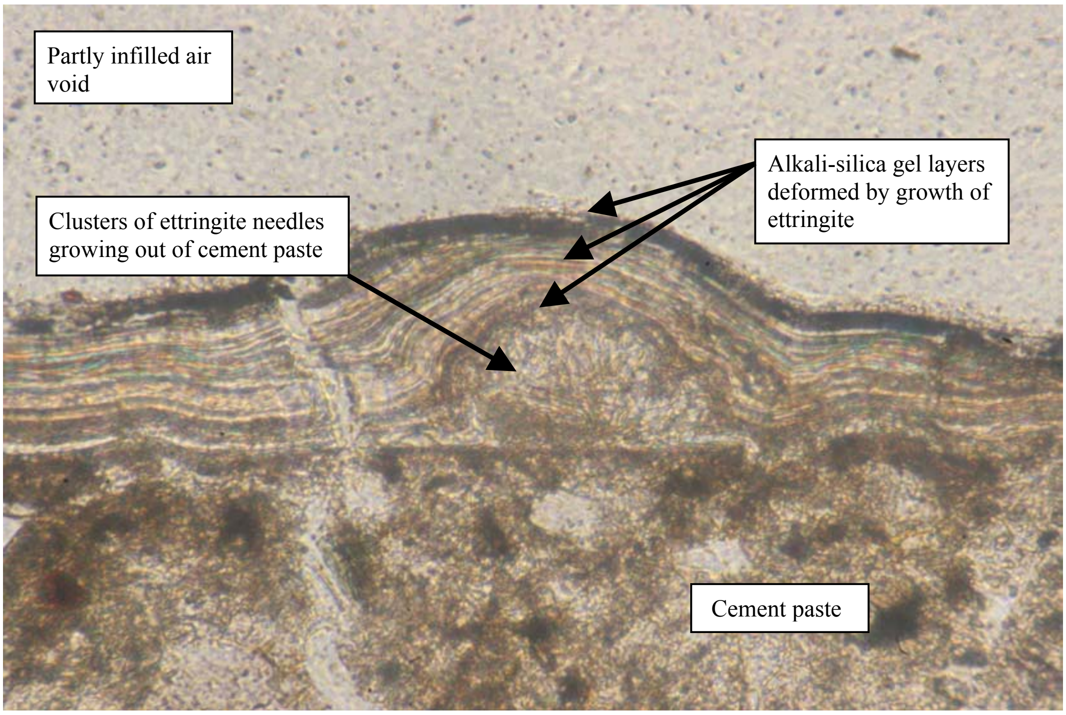

Plate 24 - Layered Alkali-silica Gel Disrupted by Outgrowth of Ettringite on Lining of an Air Void (PPL, Field of View = 1.44 mm, IMG_2290, A0B, 1060 - 1080 mm, Horizontal)

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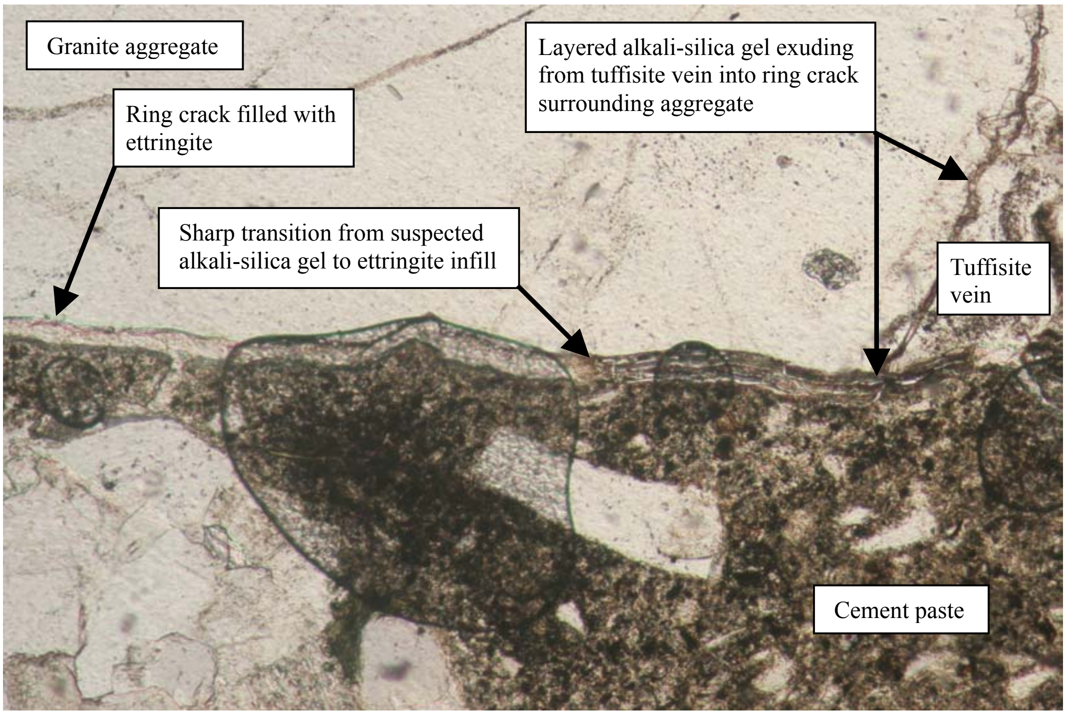

Plate 25 - Layered Alkali-silica Gel Lining Ring Crack on Aggregate Which Has Been Partly Replaced by Ettringite (PPL, Field of View = 1.44 mm, IMG_0005, A1G, 240 - 250 mm, Horizontal)

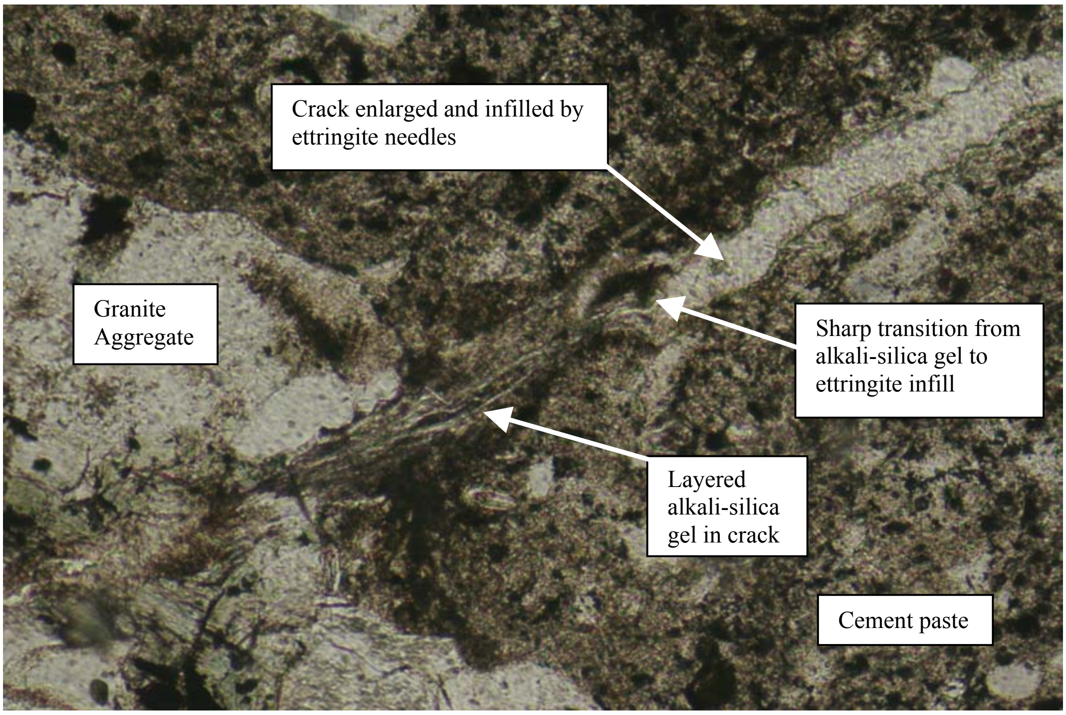

Plate 26 - Layered Alkali-silica Gel Filling Crack in Cement Paste Which Has Been Partly Replaced by Growth of Ettringite Possibly Causing Further Enlargement (PPL, Field of View = 0.72 mm, IMG_0017, A1G, 240 - 250 mm, Horizontal)

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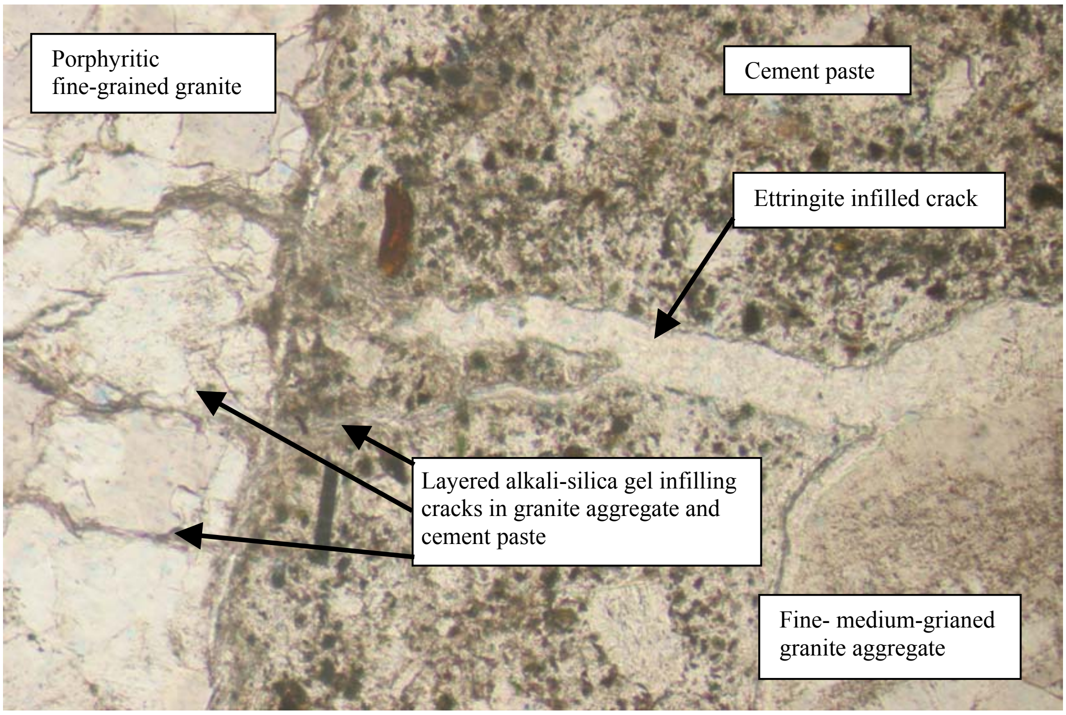

Plate 27a - Multiple Cracks Containing Layered Alkali-silica Gel in Aggregate Emanating into Cement Paste. Gel Infilled Crack is Truncated by a Crack Infilled with Ettringite (PPL, Field of View = 0.72 mm, IMG_2147, A1G, 240 - 250 mm, Horizontal)

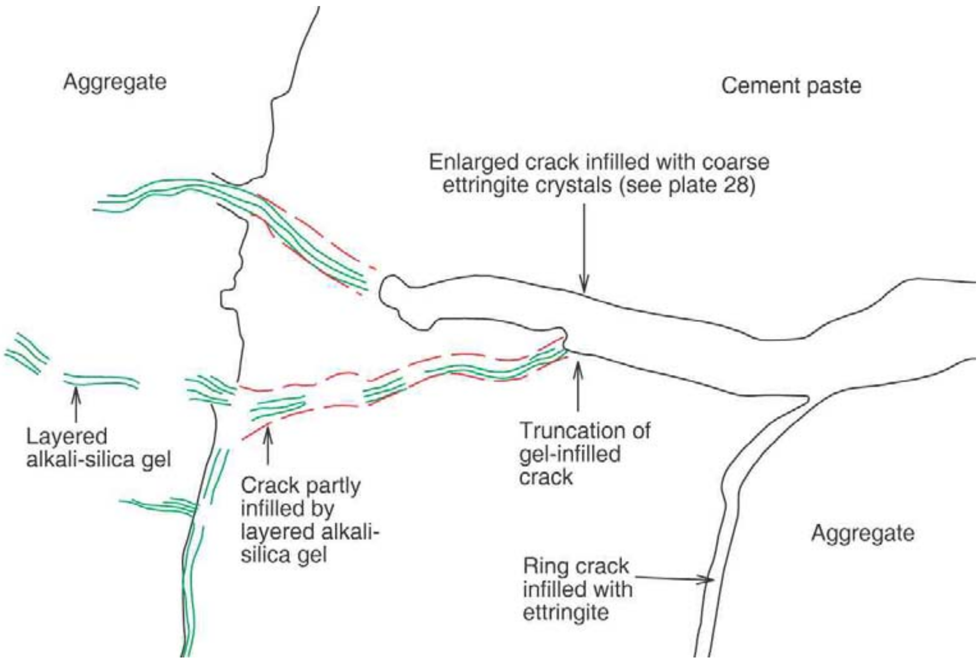

Plate 27b - Sketch of Features Shown in Plate 27a. Note Larger Crack Infilled with Ettringite Appears to Cross-cut an Earlier Crack Infilled with Layered Gel

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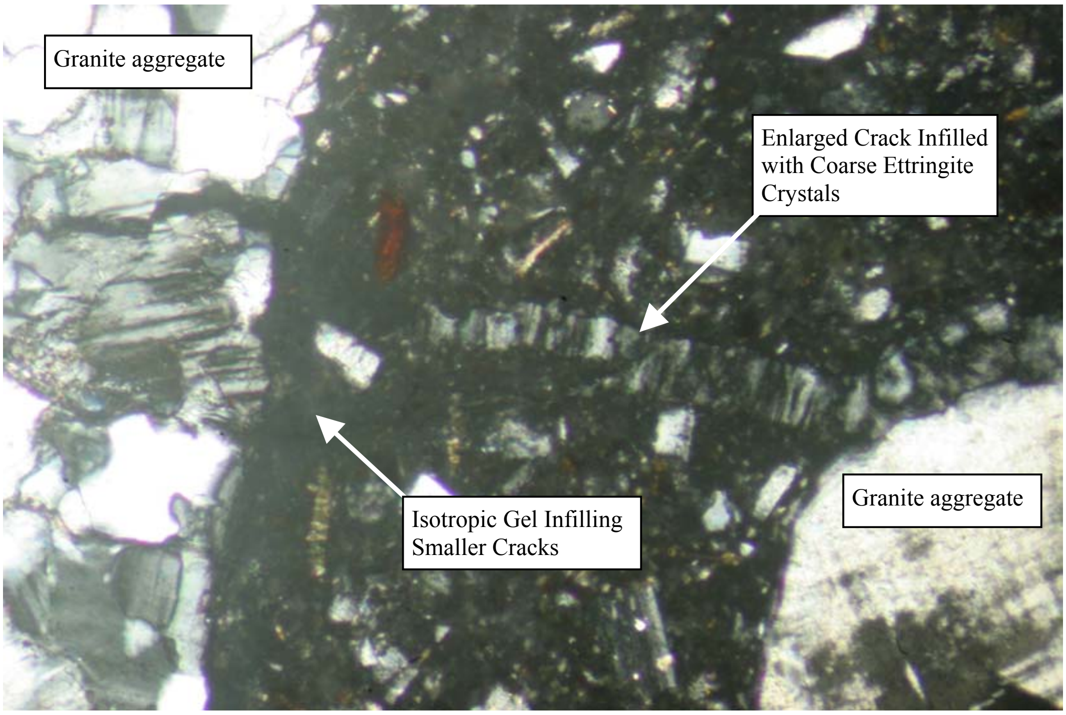

Plate 28 - Similar View as Plate 27a. Note Coarse Ettringite Crystals Produced by "Ostwald Ripening" Oriented Perpendicular to Crack Margins (CPL, Field of View = 0.72 mm, IMG_2147, A1G, 240 - 250 mm, Horizontal)

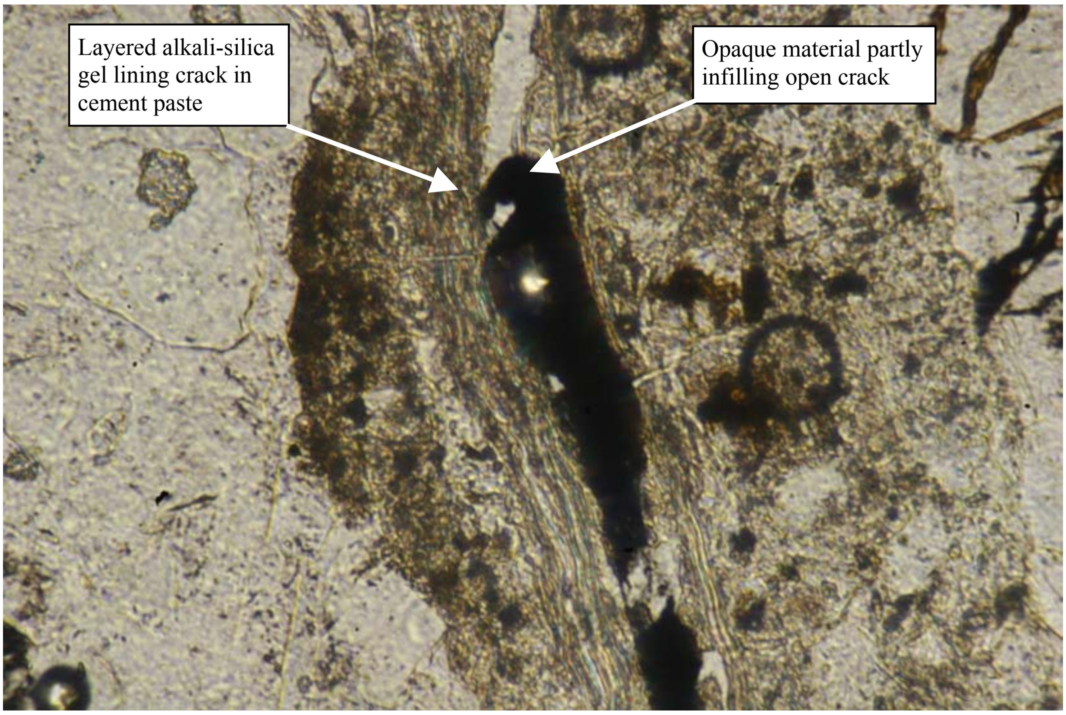

Plate 29 - Layered Alkali-silica Gel in Crack Which Has Remained Opened and Partly Infilled with Opaque Material (PPL, Field of View = 0.72 mm, IMG_2395, A1C, 180 - 240 mm, Vertical)

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APPENDIX 1

DESCRIPTIONS OF THIN SECTIONS AND POLISHED SLABS

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WW28 (CH6) - Control Block

B1C 20-30 mm (horizontal section)

Thin Section - Coarse (10-20 mm) and fine (5-8 mm) aggregates are composed of fine to medium-grained granite and porphyritic fine-grained granite (some weakly recrystallized). Sand is composed of granitic rock fragments, quartz and feldspar crystals. About 10% of the cement paste is carbonated mainly near the edge of the slide and surrounding some aggregates. The cement paste is well hydrated (W/C = 0.55). Some minor (<0.05 mm) cracks in the cement paste and ring cracks surrounding aggregate particles are present and are unfilled. PFA spheres are scattered through the cement paste. Occasional air voids are present. There is no obvious ettringite present. Minor steel fibres are present in the cement paste.

Polished Slab - Coarse and fine aggregates are composed of porphyritic fine-grained granite and fine to medium-grained granite. Sand is composed of granitic rock fragments, quartz and feldspar crystals. Occasional small (0.2-0.5 mm) air voids are internally bordered with possible ettringite. Larger (c. 2 mm) air voids are resin-infilled. Occasional ring cracks surround aggregate particles and there are minor (<0.1 mm) cracks in the cement paste. Grey cement paste when wet.

B1D 65-75 mm (horizontal section)

Thin Section - Coarse (10-20 mm) aggregates are composed of porphyritic fine-grained granite (some weakly recrystallized). Fine (5-8 mm) aggregates are composed of fine to medium-grained granite and porphyritic fine-grained granite (some weakly recrystallized). Sand is composed of granitic rock fragments, quartz and feldspar crystals. About 10% of the cement paste is carbonated mainly near the edge of the slide. The cement paste is well hydrated (W/C = 0.55). Only a few air voids are present and are resin-infilled. PFA spheres are scattered through the cement paste. A few minor (<0.05 mm) cracks are present in the cement paste and ring cracks surrounding aggregate particles are unfilled. There is no obvious ettringite present.

Polished Slab - Coarse and fine aggregates are composed of porphyritic fine-grained granite and fine to medium-grained granite. Sand is composed of granitic rock fragments, quartz and feldspar crystals. Occasional resin-infilled air voids are present. A few ring cracks surrounding aggregate particles are present and may be infilled with trace amounts of ettringite. Grey cement paste when wet.

B1E 135-145 mm (horizontal section)

Thin Section - Coarse (10-20 mm) and fine (5-8 mm) aggregates are composed of fine to medium-grained granite and porphyritic fine-grained granite (some weakly recrystallized). Sand is composed of granitic rock fragments, quartz and feldspar crystals. About 10% of the cement paste is carbonated mainly near the edge of the slide. The cement paste is well hydrated (W/C = 0.55). Only a few air voids are present and are resin-infilled. A few cracks in the cement paste interconnect with aggregates, and some ring cracks surrounding aggregate particles are resin-infilled. PFA spheres are scattered through the cement paste. There is no obvious ettringite present.

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Polished Slab - Coarse and fine aggregates are composed of porphyritic fine-grained granite and fine to medium-grained granite. Sand is composed of granitic rock fragments, quartz and feldspar crystals. A few air voids are internally bordered with possible ettringite while a few others are unfilled. A few ring cracks surrounding aggregate particles are present and some of which may be infilled with ettringite. Grey cement paste when wet.

B2B 240-250 mm (horizontal section)

Thin Section - Coarse (10-20 mm) and fine (5-8 mm) aggregates are composed of fine to medium-grained granite and porphyritic fine-grained granite (some weakly recrystallized). Sand is composed of granitic rock fragments, quartz and feldspar crystals. About 10% of the cement paste is carbonated mainly near edge of the slide. The cement paste is very well hydrated (W/C = 0.55). PFA spheres are scattered through the cement paste. A few small (c. 0.2 mm) air voids and occasional a larger (c. 4 mm) one are present and are resin-infilled. Cracks (<0.05 mm) in the cement paste interconnect with aggregates, and ring cracks surrounding aggregate particles are unfilled. There is no obvious ettringite present. Minor steel fibres are present in the cement paste.

Polished Slab - Coarse and fine aggregates are composed of porphyritic fine-grained granite and fine to medium-grained granite. Sand is composed of granitic rock fragments, quartz and feldspar crystals. A few air voids are internally bordered with possible ettringite. Some minor (<0.1 mm) cracks are present in the cement paste (some connect with aggregates) which exhibit ring cracks. Grey cement paste when wet.

B1A 0-60 mm (vertical section)

Thin Section - Coarse (10-20 mm) aggregates are composed of inequigranular fine-grained granite and porphyritic (occasional megacrystic) fine-grained granite (some weakly recrystallized). Fine (5-8 mm) aggregates are composed of fine to medium-grained granite, inequigranular fine-grained granite and porphyritic fine-grained granite (some weakly recrystallized). Sand is composed of granitic rock fragments, quartz and feldspar crystals. About 10% of the cement paste is carbonated mainly near top of the slide and occasional air voids. The cement paste is well hydrated (W/C = 0.55). PFA spheres are scattered through the cement paste. A few ring cracks surrounding aggregate particles and cracks in the cement paste are present. Occasional air voids are present. There is no obvious ettringite present.

Polished Slab - Coarse and fine aggregates are composed of porphyritic fine-grained granite and fine to medium-grained granite. Sand is composed of granitic rock fragments, quartz and feldspar crystals. A few air voids are present and are resin-infilled. Minor (<0.1 mm) cracks are present in the cement paste interconnect with aggregates, and ring cracks surrounding aggregate particles are present, some may be infilled with resin. Grey cement paste when wet.

B1B 75-135 mm (vertical section)

Thin Section - Coarse (10-20 mm) aggregates are composed of fine to medium-grained granite and porphyritic fine-grained granite (some weakly recrystallized). Fine (5-8 mm) aggregates are composed of fine to medium-grained granite, inequigranular fine-grained

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granite, porphyritic fine-grained granite (some weakly recrystallized) and an occasional tuffisite fragment. Sand is composed of granitic rock fragments, quartz and feldspar crystals. Feldspar shows granophyric texture. About 5% of the cement paste is carbonated. The cement paste is well hydrated (W/C = 0.55). PFA spheres are scattered through the cement paste. A few minor (<0.05 mm) cracks in the cement paste and ring cracks surrounding aggregate particles are unfilled. Occasional air voids are present. Minor steel fibres are present in the cement paste. There is no obvious ettringite present.

Polished Slab - Coarse aggregates are composed of porphyritic fine-grained granite and fine to medium-grained granite. Fine aggregates are composed of porphyritic fine-grained granite and granitic rock fragments. Sand is composed of granitic rock fragments, quartz and feldspar crystals. Occasional air voids (1-2 mm) are bordered with possible ettringite. Many minor (<0.1 mm) cracks are present in the cement paste (some connect with aggregates) along with ring cracks surrounding aggregate particles. Grey cement paste when wet.

B2A 180-240 mm (vertical section)

Thin Section - Coarse (10-20 mm) aggregates are composed of porphyritic fine-grained granite (some weakly recrystallized). Fine (5-8 mm) aggregates are composed of fine to medium-grained granite and porphyritic fine-grained granite (some weakly recrystallized). Sand is composed of granitic rock fragments, quartz and feldspar crystals. About 10% of the cement paste is carbonated mainly near the bottom of the slide and air voids. The cement paste is well hydrated (W/C = 0.55). PFA spheres are scattered through the cement paste. Some minor (<0.05 mm) cracks in the cement paste and ring cracks surrounding aggregate particles are present and infilled with resin. A few resin-infilled air voids are also present.

Polished Slab - Coarse and fine aggregates are composed of porphyritic fine-grained granite and fine to medium-grained granite. Sand is composed of granitic rock fragments, quartz and feldspar crystals. A couple of unfilled air voids (c. 0.5 mm) are present. Some ring cracks surrounding aggregate particles and a few minor (<0.1 mm) cracks in the cement paste are present. Grey cement paste when wet.

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WW3 (CH9)

B8D 20-30 mm (horizontal section)

Thin Section - Coarse (10-20 mm) and fine (5-8 mm) aggregates are composed of porphyritic fine-grained granite (some weakly recrystallized) and fine to medium-grained granite. Fine aggregates also composed of quartz microdiorite. Sand is composed of granitic rock fragments, quartz and feldspar crystals. About 10% of the cement paste is carbonated near cracks, air voids and the edge of the slide. The cement paste is well hydrated (W/C = 0.6). A few minor (<0.1 mm) cracks are present in the cement paste and occasional ring cracks surrounding aggregate particles are partly infilled with ettringite. Small (c. 1 mm) air voids are internally bordered with ettringite. Minor steel fibres are present in the cement paste.

Polished Slab - Coarse aggregates are composed of fine to medium-grained granite and porphyritic fine-grained granite. Fine aggregates are composed of granitic rock fragments and porphyritic fine-grained granite. Sand is composed of granitic and occasional mafic rock fragments, quartz and feldspar crystals. Occasional minor (<0.1 mm) cracks are present in the cement paste and in ring cracks surrounding aggregate particles. A major crack (1 mm) in the cement paste, passes through a few aggregates and connects with ring cracks surrounding aggregate particles and air voids. Occasional air voids are internally bordered with possible ettringite. Light grey cement paste when wet.

B8E 60-75 mm (horizontal section)

Thin Section - Coarse (10-20 mm) aggregates are rare and are composed of porphyritic fine-grained granite (some weakly recrystallized) and fine to medium-grained granite. Fine (5-8 mm) aggregates are composed of porphyritic fine-grained granite (some weakly recrystallized), fine to medium-grained granite and quartz microdiorite. Some feldspars show granophyric texture. Sand is composed of granitic rock fragments, quartz and feldspar crystals. About 10% of the cement paste is carbonated near cracks and the edge of the slide. The cement paste is well hydrated (W/C = 0.6). Some minor (<0.1 mm) cracks are present in the cement paste (some connect with ring cracks surrounding aggregate particles). Many ring cracks surrounding aggregate particles are commonly completely infilled with ettringite. Air voids (0.2-0.4 mm) are internally bordered, occasional completely infilled, with ettringite. There is no obvious alkali-silica gel present. Minor steel fibres are present in the cement paste.

Polished Slab - Coarse aggregates are composed of fine to medium-grained granite and mafic rock fragments. Fine aggregates are composed of granitic and occasional mafic rock fragments and porphyritic fine-grained granite. Sand is composed of granitic and occasional mafic rock fragments, quartz and feldspar crystals. Some minor (<0.1 mm) cracks in the cement paste and ring cracks surrounding aggregate particles may be infilled with ettringite and alkali-silica gel. Air voids are commonly internally bordered with possible ettringite. Light grey cement paste when wet.

B8F 170-180 mm (horizontal section)

Thin Section - Coarse (10-20 mm) and fine (5-8 mm) aggregates are composed of porphyritic fine-grained granite (some weakly recrystallized) and fine to medium-grained granite. Sand

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is composed of granitic rock fragments, quartz and feldspar crystals. About 15% of the cement paste is carbonated near cracks and the edge of the slide. The cement paste is very well hydrated (W/C = 0.6). Some minor (<0.1 mm) cracks are present in the cement paste (some connect with ring cracks surrounding aggregate particles). Many of the ring cracks surrounding aggregate particles are completely infilled with ettringite. Air voids are commonly bordered or completely infilled with ettringite. Layered alkali-silica gel appears to infill some cracks but may be partly altered.

Polished Slab - Coarse aggregates are composed of porphyritic fine-grained granite. Fine aggregates are composed of porphyritic fine-grained granitic and mafic rock fragments. Sand is composed of granitic and mafic rock fragments, quartz and feldspar crystals. Some ring cracks surrounding aggregate particles may be infilled with ettringite. Occasional air voids are internally bordered with possible ettringite. Light grey cement paste when wet.

B8A 0-60 mm (vertical section)

Thin Section - Coarse (10-20 mm) and fine (5-8 mm) aggregates are composed of porphyritic fine-grained granite (some weakly recrystallized), fine to medium-grained granite and quartz microdiorite. Sand is composed of granitic rock fragments, quartz microdiorite, quartz and feldspar crystals. Very minor amounts of the cement paste are carbonated near the top of the slide. The cement paste is well hydrated (W/C = 0.6). A few minor (<0.1 mm) cracks are present in the cement paste (some connect with ring cracks surrounding aggregate particles) and many ring cracks are infilled with ettringite. Air voids are common and are bordered, sometimes completely infilled, with ettringite. There is no obvious alkali-silica gel present. Minor steel fibres are present in the cement paste.

Polished Slab - Coarse aggregates are composed of fine to medium-grained granite, porphyritic fine-grained granite and occasional mafic rock fragments. Fine aggregates are composed of mafic rock fragments and porphyritic fine-grained granite. Sand is composed of granitic rock fragments, quartz and feldspar crystals. A few minor (<0.1 mm) cracks are present in the cement paste and ring cracks surrounding aggregate particles may be infilled with ettringite. Air voids are internally bordered, occasionally completely infilled, with possible ettringite. Light grey cement paste when wet.

B8B 75-135 mm (vertical section)

Thin Section - Coarse (10-20 mm) aggregates are composed of porphyritic fine-grained granite (some weakly recrystallized). Fine (5-8 mm) aggregates are composed of porphyritic fine-grained granite (some weakly recrystallized) and fine to medium-grained granite. One granite aggregate particles appears to be weakly cataclasised. Sand is composed of granitic rock fragments, quartz microdiorite, quartz and feldspar crystals. About 20% of the cement paste is carbonated mostly near cracks. The cement paste is well hydrated (W/C = 0.6). Some minor (<0.1 mm) cracks are present in the cement paste (some connect with ring cracks surrounding aggregate particles) and ring cracks are commonly completely infilled with ettringite. Air voids are commonly bordered, some completely infilled, with ettringite. Layered gel appears to infill some cracks but may be altered. Minor steel fibres are present in the cement paste.

Polished Slab - Coarse aggregates are composed of porphyritic fine-grained granite. Fine

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aggregates are composed of porphyritic fine-grained granitic and mafic rock fragments. Sand is composed of granitic and mafic rock fragments, quartz and feldspar crystals. A few minor (<0.1 mm) cracks in the cement paste and some ring cracks surrounding aggregate particles may be infilled with ettringite. Air voids are commonly internally bordered with possible ettringite. Light grey cement paste when wet.

B8C 180-240 mm (vertical section)

Thin Section - Coarse (10-20 mm) and fine (5-8 mm) aggregates are composed of porphyritic fine-grained granite (some weakly recrystallized) and fine to medium-grained granite. Sand is composed of granitic rock fragments, quartz and feldspar crystals. About 20% of the cement paste is carbonated near cracks and scattered throughout the slide. The cement paste is very well hydrated (W/C = 0.6). Some minor (<0.1 mm) cracks in the cement paste (some connect with ring cracks surrounding aggregate particles) and ring cracks are commonly infilled with ettringite. Air voids are bordered or completely infilled with ettringite. There is no obvious alkali-silica gel present. Minor steel fibres are present in the cement paste.

Polished Slab - Coarse aggregates are composed of fine to medium-grained granite and porphyritic fine-grained granite. Fine aggregates are composed of granitic and mafic rock fragments and porphyritic fine-grained granite. Sand is composed of granitic rock fragments, quartz and feldspar crystals. A few minor (<0.1 mm) cracks in the cement paste and ring cracks surrounding aggregate particles may be infilled with ettringite. Air voids are common and are commonly internally bordered or completely infilled with possible ettringite. Light grey cement paste when wet.

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WW5 (CH7)

B3C 20-30 mm (horizontal section)

Thin Section - Coarse (10-20 mm) and fine (5-8 mm) aggregates are composed of porphyritic fine-grained granite (some weakly recrystallized) and fine to medium-grained granite. Sand is composed of granitic rock fragments, quartz and feldspar crystals. About 20% of the cement paste is carbonated mostly near cracks and the edge of the slide. The cement paste is well hydrated (W/C = 0.55). A few minor (c. 0.05 mm) cracks are present in the cement paste, occasionally along aggregate surfaces and within aggregates. They appear to be resin-infilled. Ettringite borders and infills air voids, and infills cracks. There is no obvious alkali-silica gel present. Minor steel fibres are present in the cement paste.

Polished Slab - Coarse aggregates are composed of porphyritic fine-grained granite and fine to medium-grained granite. Fine aggregates are composed of porphyritic fine-grained granite and granitic rock fragments. Sand is composed of mafic rock fragments, quartz and feldspar crystals. A crack (0.5 mm) in the cement paste, which connects with aggregate surfaces, may contain some alkali-silica gel. A few minor (<0.1 mm) cracks are present in the cement paste. Most of the air voids appear to be infilled, possibly with ettringite or alkali-silica gel. Light greenish grey cement paste when wet.

B3D 65-75 mm (horizontal section)

Thin Section - Coarse (10-20 mm) and fine (5-8 mm) aggregates are composed of porphyritic fine-grained granite (weakly recrystallized) and fine to medium-grained granite. Coarse aggregates also composed of quartz microdiorite. Fine aggregates also composed of minor tuffisite veins. Sand is composed of granitic rock fragments, quartz and feldspar crystals. About 20% of the cement paste is carbonated mostly near cracks and the edge of the slide, and surrounding aggregates. The cement paste is well hydrated (W/C = 0.55). Some minor (<0.1 mm) cracks are present in the cement paste and connect with ring cracks surrounding aggregate particles, and are infilled with ettringite. Ettringite borders large (c. 2 mm) air voids and infills smaller (c. 0.1 mm) ones, and borders ring cracks. There is no obvious alkali-silica gel present. Minor steel fibres are present in the cement paste.

Polished Slab - Coarse and fine aggregates are composed of porphyritic fine-grained granite, fine to medium-grained granite and mafic rock fragments. Sand is composed of occasional granitic rock fragments, quartz and feldspar crystals. Many ring cracks surrounding aggregate particles and cracks (c. 0.1 mm) in the cement paste, which connect aggregate surfaces, may be infilled or bordered with ettringite and/or alkali-silica gel. Most air voids are bordered with possible ettringite. Light greenish grey cement paste when wet.

B3E 135-145 mm (horizontal section)

Thin Section - Coarse (10-20 mm) aggregates are composed of porphyritic fine-grained granite (weakly recrystallized), fine to medium-grained granite and quartz microdiorite. Fine (5-8 mm) aggregates are composed of porphyritic fine-grained granite (weakly recrystallized), inequigranular fine-grained granite, fine to medium-grained granite and quartz microdiorite. Sand is composed of granitic rock fragments, quartz and feldspar crystals. Some feldspars show granophyric texture. About 5% of the cement paste is carbonated mostly near the edge of the slide. The cement paste is well hydrated (W/C = 0.55). Some cracks are present in the cement paste, along aggregate surfaces and within aggregates. Ettringite borders large (c. 0.5 mm) air voids and infills smaller (c. 0.1 mm) ones, and borders ring cracks surrounding aggregate particles. Thin layers of alkali-silica gel are present bordering an air void, and appear to have been subsequently disrupted by growth of ettringite.

Polished Slab - Coarse aggregates are composed of porphyritic fine-grained granite. Fine aggregates are composed of porphyritic fine-grained granitic rock fragments. Sand is composed of granitic rock fragments, quartz and feldspar crystals. Some minor (<0.1 mm) cracks in the cement paste, which connect with aggregates, are infilled with possible ettringite and alkali-silica gel. Ring cracks surrounding aggregate particles are common and infilled with possible ettringite. Occasional ring cracks surrounding aggregate particles may be surrounded by alkali-silica gel. Air voids are bordered with possible ettringite and occasional alkali-silica gel. Light greenish grey cement paste when wet.

B4B 240-250 mm (horizontal section)

Thin Section - Coarse (10-20 mm) aggregates are composed of porphyritic fine-grained granite (weakly recrystallized), fine to medium-grained granite and quartz microdiorite. Fine (5-8 mm) aggregates are composed of porphyritic fine-grained granite, fine to medium-grained granite and a fragment of tuffisite (probably from a vein). Sand is composed of granitic rock fragments, quartz and feldspar crystals (some strained). Minor amounts of the cement paste are carbonated mostly near cracks and the edge of the slide. The cement paste is well hydrated (W/C = 0.55). Cracks in the cement paste connect with aggregates and are partly infilled with ettringite. Cracks within aggregates are common and some are infilled with dried or recrystallised alkali-silica gel. One gel infilled crack appears to emanate into the cement paste from a tuffisite vein within an aggregate particle. Ettringite commonly borders large (c. 1 mm) air voids and infills smaller (c. 0.1 mm) ones, and commonly infills or borders ring cracks surrounding aggregate particles. Minor steel fibres are present in the cement paste.

Polished Slab - Coarse aggregates are composed of porphyritic fine-grained granite and fine to medium-grained granite. Fine aggregates are composed of porphyritic fine-grained granite. Sand is composed of granitic rock fragments, quartz and feldspar crystals. Some minor (<0.1 mm) cracks in the cement paste and ring cracks surrounding aggregate particles are infilled with possible ettringite. Cracks within aggregates are common and are unfilled. Large (1-2 mm) air voids are bordered and smaller (0.2-0.5 mm) ones are completely infilled with possible ettringite. Trace amounts of possible alkali-silica gel may be present near aggregate surfaces and within a few minor (<0.1 mm) cracks. Grey cement paste when wet.

B5B 1010-1020 mm (horizontal section)

Thin Section - Coarse (10-20 mm) aggregates are composed of porphyritic fine-grained granite (weakly recrystallized). Fine (5-8 mm) aggregates are composed of porphyritic fine-grained granite (some weakly recrystallized), fine to medium-grained granite, occasional fine-grained granite and tuffisite veins. Sand is composed of granitic rock fragments, quartz and feldspar crystals. The cement paste is weakly carbonated throughout the slide and is well hydrated (W/C = 0.55). Cracks are commonly present in the cement paste and connect ring cracks surrounding aggregate particles and are infilled with ettringite. Ettringite

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occasionally borders air voids and commonly infills cracks in the cement paste and ring cracks. Alkali-silica gel, sometime showing conchoidal desiccation cracks, is present in a crack (which passes through an aggregate) in the cement paste.

Polished Slab - Coarse aggregates are composed of porphyritic fine-grained granite and fine to medium-grained granite. Fine aggregates are composed of porphyritic fine-grained granite, fine-grained granite and mafic rock fragments. Sand is composed of granitic and mafic rock fragments, quartz and feldspar crystals. A few minor (<0.1 mm) cracks in the cement paste, which connect with aggregates, are infilled with possible ettringite. Ring cracks surrounding aggregate particles are common and possibly infilled with ettringite. A few minor (<0.1 mm) cracks within aggregates are unfilled. Large (1-2 mm) and small (0.2 mm) air voids are commonly bordered with possible ettringite. A few ring cracks surrounding aggregate particles and cracks in the cement paste may contain alkali-silica gel. Grey cement paste when wet.

B3A 0-60 mm (vertical section)

Thin Section - Coarse (10-20 mm) aggregates are composed of porphyritic fine-grained granite and fine to medium-grained granite. Fine (5-8 mm) aggregates are composed of porphyritic fine-grained granite, fine to medium-grained granite and occasional quartz microdiorite. Sand is composed of granitic rock fragments, quartz and feldspar crystals (some strained). Minor amounts of the cement paste are carbonated mostly near the top and bottom of the slide. The cement paste is well hydrated (W/C = 0.55). A few minor (<0.05 mm) cracks are present in the cement paste. Ettringite borders large (1-4 mm) air voids and occasionally completely infills smaller (c. 0.1 mm) ones. There is no obvious alkali-silica gel present.

Polished Slab - Coarse aggregates are composed of porphyritic fine-grained granite and fine to medium-grained granite. Fine aggregates are composed of porphyritic fine-grained granite, granitic and mafic rock fragments. Sand is composed of granitic and mafic rock fragments, quartz and feldspar crystals. A few cracks in the cement paste and ring cracks surrounding aggregate particles are commonly infilled with possible ettringite. A few air voids (0.2-0.5 mm) are bordered with possible ettringite while larger (1-2 mm) ones are unfilled. Light greenish grey cement paste when wet.

B3B 75-135 mm (vertical section)

Thin Section - Coarse (10-20 mm) aggregates are composed of porphyritic fine-grained granite (weakly recrystallized), fine to medium-grained granite and quartz microdiorite. Fine (5-8 mm) aggregates are composed of porphyritic fine-grained granite, fine-grained granite and quartz microdiorite. Sand is composed of granitic rock fragments, quartz and feldspar crystals. About 5% of the cement paste is carbonated mostly near air voids and the edge of the slide. The cement paste is well hydrated (W/C = 0.55). Some cracks within aggregates are unfilled. A few minor (<0.1 mm) cracks in the cement paste, which connect with ring cracks surrounding aggregate particles, are infilled with ettringite. Ettringite commonly borders large (c. 2 mm) air voids and completely infills smaller (c. 0.2 mm) ones, and borders ring cracks. There is no obvious alkali-silica gel present.

Polished Slab - Coarse aggregates are composed of porphyritic fine-grained granite, fine to

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medium-grained granite and occasional mafic rock fragments. Fine aggregates are composed of porphyritic fine-grained granitic rock fragments. Sand is composed of granitic and mafic rock fragments, quartz and feldspar crystals. Many minor (<0.1 mm) cracks are present in the cement paste, which connect with aggregates, and ring cracks surrounding aggregate particles may be infilled with ettringite. Air voids are bordered with possible ettringite. Light greenish grey cement paste when wet.

B4A 180-240 mm (vertical section)

Thin Section - Coarse (10-20 mm) aggregates are composed of porphyritic fine-grained granite (weakly recrystallized) and quartz microdiorite. Fine (5-8 mm) aggregates are composed of porphyritic fine-grained granite, fine to medium-grained granite and feldspar crystals. Sand is composed of granitic rock fragments, quartz and feldspar crystals. Minor amounts of the cement paste are carbonated mostly near air voids and the bottom of the slide. The cement paste is well hydrated (W/C = 0.55). Cracks (c. 0.1 mm) are present in the cement paste, within aggregates and in ring cracks surrounding aggregate particles. Ettringite commonly borders large (c. 2 mm) air voids and sometimes completely infills smaller (c. 0.2 mm) ones, and borders cracks in the cement paste and ring cracks. Layered alkali-silica gel showing desiccation cracking is present in cracks in the cement paste and within some aggregates.

Polished Slab - Coarse aggregates are composed of porphyritic fine-grained granite and occasional fine to medium-grained granite. Fine aggregates are composed of porphyritic fine-grained granite, granitic and mafic rock fragments. Sand is composed of granitic and mafic rock fragments, quartz and feldspar crystals. Minor (<0.1 mm) cracks in the cement paste (some connect with aggregates) and ring cracks surrounding aggregate particles are infilled with possible ettringite. Air voids are bordered with possible ettringite. Some possible alkali-silica gel is present along minor (<0.1 mm) cracks locally, and surrounding occasional air voids. Light greenish grey cement paste when wet.

B5A 950-1010 mm (vertical section)

Thin Section - Coarse (10-20 mm) aggregates are composed of porphyritic fine-grained granite (weakly recrystallized) and fine to medium-grained granite. Fine (5-8 mm) aggregates are composed of porphyritic fine-grained granite and fine to medium-grained granite. Sand is composed of granitic rock fragments, quartz and feldspar crystals (some strained). About 20% of the cement paste is carbonated mostly near the edge of the slide. The cement paste is well hydrated (W/C = 0.55). Cracks are present in the cement paste and along aggregate surfaces, and within a few aggregates. Ring cracks surrounding aggregate particles and cracks in the cement paste are common, and are infilled with ettringite. Some cracks are present within aggregates and are unfilled. Ettringite borders large (2-4 mm) air voids and sometimes completely infills smaller (0.1-0.2 mm) ones, and commonly borders cracks. Layered alkali-silica gel, showing desiccation cracks, is occasionally observed infilling cracks in the cement paste.

Polished Slab - Coarse and fine aggregates are composed of porphyritic fine-grained granite and fine to medium-grained granite. Sand is composed of granitic and mafic rock fragments, quartz and feldspar crystals. Some minor (<0.1 mm) cracks in the cement paste (some connect with aggregates) and ring cracks surrounding aggregate particles are unfilled. Air

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voids are bordered, and occasionally completely infilled, with possible ettringite. Grey cement paste when wet.

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WW9A (CH3)

A5B 20-30 mm (horizontal section)

Thin Section - Coarse (10-20 mm) and fine (5-8 mm) aggregates are composed of porphyritic fine-grained granite, fine to medium-grained granite and quartz microdiorite. Sand is composed of granitic rock fragments, quartz and feldspar crystals. About 10% of the cement paste is carbonated mainly along cracks (in particular a 1 mm crack) and near the edge of the slide. The cement paste is well hydrated (W/C = 0.55). A few minor (<0.05 mm) cracks in the cement paste and ring cracks surrounding aggregate particles are present, some of which are bordered with ettringite. Air voids are commonly internally bordered, some smaller (c. 0.2 mm) ones are completely infilled, with ettringite. There is no obvious alkali-silica gel present. Minor steel fibres are present in the cement paste.

Polished Slab - Coarse aggregates are composed of fine to medium-grained granite, porphyritic fine-grained granite and mafic rock fragments. Fine aggregates are composed of granitic and mafic rock fragments and porphyritic fine-grained granite. Sand is composed of granitic rock fragments, quartz and feldspar crystals. A few minor (<0.1 mm) cracks in the cement paste may contain alkali-silica gel. A major (0.5-2 mm) crack in the cement paste, which connects with an aggregate surface, is resin-infilled. Many air voids are present but only occasional smaller (<0.2 mm) ones are bordered with possible ettringite. Grey cement paste when wet.

A6B 65-75 mm (horizontal section)

Thin Section - Coarse (10-20 mm) aggregates are composed of porphyritic fine-grained granite (some weakly recrystallized), fine to medium-grained granite and quartz microdiorite. Fine (5-8 mm) aggregate are composed of porphyritic fine-grained granite. Sand is composed of granitic and occasional mafic rock fragments, quartz and feldspar crystals. Some feldspars show granophyric texture. About 10% of the cement paste is carbonated near the edge of the slide. The cement paste is well hydrated (W/C = 0.55). A few minor (<0.1 mm) cracks in the cement paste and ring cracks surrounding aggregate particles are present and are bordered with ettringite. Air voids are commonly internally bordered, some completely infilled, with ettringite. Layered alkali-silica gel infills some cracks in the cement paste. Minor steel fibres are present in the cement paste.

Polished Slab - Coarse aggregates are composed of fine to medium-grained granite, porphyritic fine-grained granite and mafic rock fragments. Fine aggregates are composed of granitic and mafic rock fragments and porphyritic fine-grained granite. Sand is composed of granitic rock fragments, quartz and feldspar crystals. Some minor (<0.1 mm) cracks in the cement paste (some connect with ring cracks surrounding aggregate particles) and a few ring cracks surrounding aggregate particles appear to be infilled with ettringite. Air voids are commonly internally bordered, occasional some smaller (<0.2 mm) ones are completely infilled, with possible ettringite. Grey cement paste when wet.

A6C 1060-1070 mm (horizontal section)

Thin Section - Coarse (10-20 mm) and fine (5-8 mm) aggregates are composed of porphyritic fine-grained granite (some weakly recrystallized) and fine to medium-grained granite. Coarse aggregates also composed of quartz microdiorite. Sand is composed of granitic rock

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fragments, quartz and feldspar crystals. Some feldspars show granophyric texture. About 10% of the cement paste is carbonated near the edge of the slide. The cement paste is well hydrated (W/C = 0.55). A few minor (<0.05 mm) cracks in the cement paste and many ring cracks surrounding aggregate particles are present and are bordered and commonly infilled with ettringite. Small (c. 0.2 mm) air voids are completely infilled with ettringite. Very minor layered alkali-silica gel is present infilling cracks on the edge of aggregate particles. Minor steel fibres are present in the cement paste.

Polished Slab - Coarse aggregates are composed of fine to medium-grained granite, porphyritic fine-grained granite and mafic rock fragments. Fine aggregates are composed of granitic rock fragments and porphyritic fine-grained granite. Sand is composed of granitic rock fragments, quartz and feldspar crystals. A few minor (<0.1 mm) cracks in the cement paste (some connect with ring cracks surrounding aggregate particles) and ring cracks surrounding aggregate particles may be infilled with ettringite. A few cracks within aggregates are unfilled. Occasional air voids are internally bordered with possible ettringite. Dark grey cement paste when wet.

A7B 2020-2030 mm (horizontal section)

Thin Section - Coarse (10-20 mm) and fine (5-8 mm) aggregates are composed of porphyritic fine-grained granite (some weakly recrystallized) and fine to medium-grained granite. Sand is composed of granitic rock fragments, quartz and feldspar crystals. About 10% of the cement paste is carbonated near the edge of the slide. The cement paste is well hydrated (W/C = 0.6). A few minor (<0.05 mm) cracks in the cement paste and some ring cracks surrounding aggregate particles are present and are bordered and commonly infilled with ettringite. Air voids are common and are internally bordered, commonly completely infilled, with ettringite. Multiple layers of alkali-silica gel internally border an air void. Minor steel fibres are present in the cement paste.

Polished Slab - Coarse aggregates are composed of fine to medium-grained granite and porphyritic fine-grained granite. Fine aggregates are composed of granitic rock fragments and porphyritic fine-grained granite. Sand is composed of granitic and mafic rock fragments, quartz and feldspar crystals. A few minor (<0.1 mm) cracks in the cement paste and ring cracks surrounding aggregate particles appear to be infilled with alkali-silica gel. Air voids are commonly internally bordered with possible ettringite. Grey cement paste when wet.

A5A 0-60 mm (vertical section)

Thin Section - Coarse (10-20 mm) aggregates are composed of porphyritic fine-grained granite (some weakly recrystallized), fine to medium-grained granite and fine-grained granite. Fine (5-8 mm) aggregate are composed of porphyritic fine-grained granite (some weakly recrystallized), fine to medium-grained granite and quartz microdiorite. Sand is composed of granitic rock fragments, quartz and feldspar crystals. About 15% of the cement paste is carbonated near the bottom and top of the slide. The cement paste is well hydrated (W/C = 0.55). A few minor (<0.05 mm) cracks in the cement paste and many ring cracks surrounding aggregate particles are present and are resin-infilled. Air voids are common and are internally bordered with ettringite. There is no obvious alkali-silica gel present. Minor steel fibres are present in the cement paste.

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Polished Slab - Coarse aggregates are composed of fine to medium-grained granite and porphyritic fine-grained granite. Fine aggregates are composed of granitic rock fragments and porphyritic fine-grained granite. Sand is composed of granitic rock fragments, quartz and feldspar crystals. A few minor (<0.1 mm) cracks in the cement paste. Air voids (1-2 mm) are commonly resin-infilled or unfilled. Occasional smaller (0.2 mm) ones are completely infilled with possible ettringite. Grey cement paste when wet.

A6A 1000-1060 mm (vertical section)

Thin Section - Coarse (10-20 mm) and fine (5-8 mm) aggregates are composed of porphyritic fine-grained granite (some weakly recrystallized) and fine to medium-grained granite. Fine aggregates also composed of quartz microdiorite. Sand is composed of granitic rock fragments, quartz and feldspar crystals. About 20% of the cement paste is carbonated scattered throughout the slide. The cement paste is well hydrated (W/C = 0.55). Some minor (<0.05 mm) cracks in the cement paste and ring cracks surrounding aggregate particles are bordered and commonly infilled with ettringite. Many cracks in the cement paste are present which connect with ring cracks surrounding aggregate particles and air voids. Many air voids are internally bordered, commonly completely infilled, with ettringite. Minor layered alkali-silica gel is present along the margin of an aggregate particle. Minor steel fibres are present in the cement paste.

Polished Slab - Coarse aggregates are composed of fine to medium-grained granite and porphyritic fine-grained granite. Fine aggregates are composed of granitic and mafic rock fragments and porphyritic fine-grained granite. Sand is composed of granitic rock fragments, quartz and feldspar crystals. Some minor (<0.1 mm) cracks in the cement paste and some ring cracks surrounding aggregate particles may be infilled with ettringite. Some air voids are internally bordered or completely infilled with possible ettringite. Grey cement paste when wet.

A7A 1960-2020 mm (vertical section)

Thin Section - Coarse (10-20 mm) and fine (5-8 mm) aggregates are composed of porphyritic fine-grained granite (some weakly recrystallized) and fine to medium-grained granite. Coarse aggregates also composed of quartz microdiorite. Sand is composed of granitic rock fragments, quartz and feldspar crystals. Some feldspars show granophyric texture. About 80% of the cement paste is carbonated throughout the slide. The cement paste is well hydrated (W/C = 0.55). A few minor (<0.05 mm) cracks in the cement paste and ring cracks surrounding aggregate particles are present and are resin-infilled. Air voids are common and are internally bordered with ettringite. There is no obvious alkali-silica gel present.

Polished Slab - Coarse aggregates are composed of porphyritic fine-grained granite and mafic rock fragments. Fine aggregates are composed of granitic and mafic rock fragments and porphyritic fine-grained granite. Sand is composed of granitic rock fragments, quartz and feldspar crystals. Some minor (<0.1 mm) cracks in the cement paste and a few ring cracks surrounding aggregate particles may be infilled with ettringite. Air voids are commonly internally bordered with possible ettringite. Grey cement paste when wet.

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WW9A (CH4)

A2A 20-30 mm (horizontal section)

Thin Section - Coarse (10-20 mm) aggregates are composed of porphyritic fine-grained granite (some weakly recrystallized) and fine to medium-grained granite. Fine (5-8 mm) aggregates are composed of porphyritic fine-grained granite (weakly recrystallized) and quartz microdiorite with preferred orientation of crystals. Sand is composed of granitic rock fragments, quartz and feldspar crystals. About 10% of the cement paste is carbonated near air voids and cracks. The cement paste is well hydrated (W/C = 0.55). Only a few cracks are present in the cement paste and are resin-infilled. A few air voids are internally bordered, occasionally completely infilled, with ettringite. There is no obvious alkali-silica gel present. Minor steel fibres are present in the cement paste.

Polished Slab (A2B) - Coarse aggregates are composed of porphyritic fine-grained granite. Fine aggregates are composed of porphyritic fine-grained granite, fine to medium-grained granite and granitic rock fragments. Sand is composed of granitic rock fragments, quartz and feldspar crystals. Some minor (<0.1 mm) cracks in the cement paste (some connect with aggregates) may contain alkali-silica gel. A crack (1 mm) in the cement paste, which connect with aggregate surfaces and passes through an aggregate, is resin-infilled. Air voids (0.5-2 mm) are internally bordered with possible ettringite. Dark grey cement paste when wet.

A3A 65-75 mm (horizontal section)

Thin Section - Coarse (10-20 mm) and fine (5-8 mm) aggregates are composed of porphyritic fine-grained granite (some weakly recrystallized) and fine to medium-grained granite. Sand is composed of granitic rock fragments, quartz and feldspar crystals. Occasional feldspars show granophyric texture. About 10% of the cement paste is carbonated near cracks, air voids and the edge of the slide. The cement paste is well hydrated (W/C = 0.55). Minor (<0.05 mm) cracks in the cement paste are common and appear to be resin-infilled. A crack (1 mm) is present mostly in the cement paste and connects with aggregate surface and a large (c. 4 mm) air void, and is resin-infilled. A few ring cracks surrounding aggregate particles are either bordered or infilled with ettringite. Air voids are common and are commonly internaly bordered, sometimes completely infilled, with ettringite. There is no obvious alkali-silica gel present.

Polished Slab (A3B) - Coarse aggregates are composed of porphyritic fine-grained granite and fine to medium-grained granite. Fine aggregates are rare and are composed of granitic and a few mafic rock fragments. Sand is composed of granitic rock fragments, quartz and feldspar crystals. A few minor (<0.1 mm) cracks in the cement paste and many ring cracks surrounding aggregate particles are possibly infilled with ettringite. A crack (1 mm) in the cement paste, connects with aggregate surfaces and passes through fine aggregates, is resin-infilled. Large (1-5 mm) air voids are commonly internally bordered/resin-infilled, and some smaller (c. 0.5 mm) ones are completely infilled, with possible ettringite. Dark grey cement paste when wet.

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A1A 0-60 mm (vertical section)

Thin Section - Coarse (10-20 mm) and fine (5-8 mm) aggregates are composed of porphyritic fine-grained granite (some weakly recrystallized) and fine to medium-grained granite. Fine aggregates also composed of occasional quartz microdiorite. Sand is composed of granitic rock fragments, quartz and feldspar crystals. About 10% of the cement paste is carbonated near air voids and cracks. The cement paste is well hydrated (W/C = 0.55). A few minor (<0.05 mm) cracks in the cement paste and some ring cracks surrounding aggregate particles are present and are bordered or infilled with ettringite. Air voids are internally bordered, commonly completely infilled, with ettringite. There is no obvious alkali-silica gel present. Minor steel fibres are present in the cement paste.

Polished Slab (A1B) - Coarse aggregates are composed of fine to medium-grained granite and granitic rock fragments. Fine aggregates are composed of granitic rock fragments and occasional porphyritic fine-grained granite. Sand is composed of granitic rock fragments, quartz and feldspar crystals. A few minor (<0.1 mm) cracks in the cement paste and ring cracks surrounding aggregate particles may be infilled with ettringite, and some may contain alkali-silica gel. Air voids (0.5-2 mm) are commonly internally bordered with possible ettringite. Dark grey cement paste when wet.

A4A 75-135 mm (vertical section)

Thin Section - Coarse (10-20 mm) and fine (5-8 mm) aggregates are composed of porphyritic fine-grained granite (weakly recrystallized) and fine to medium-grained granite. Sand is composed of granitic rock fragments, quartz and feldspar crystals. About 10% of the cement paste is carbonated mainly near air voids, cracks and the two sides of the slide. The cement paste is well hydrated (W/C = 0.55). Cracks in the cement paste (some connect with ring cracks surrounding aggregate particles) are common and are commonly bordered or infilled with ettringite. Some ring cracks surrounding aggregate particles are infilled with ettringite. Air voids are internally bordered, sometimes completely infilled, with ettringite. There is no obvious alkali-silica gel present. Minor steel fibres are present in the cement paste.

Polished Slab (A4B) - Coarse aggregates are composed of fine to medium-grained granite and porphyritic fine-grained granite. Fine aggregates are composed of porphyritic fine-grained granite, fine to medium-grained granite, granitic and mafic rock fragments. Sand is composed of granitic and mafic rock fragments, quartz and feldspar crystals. A few minor (<0.1 mm) cracks in the cement paste and some ring cracks surrounding aggregate particles may be infilled with ettringite. Occasional minor (<0.1 mm) cracks in the cement paste may contain alkali-silica gel. Large (3-5 mm) air voids are commonly internally bordered, some smaller (1-2 mm) ones are completely infilled, with possible ettringite. Dark grey cement paste when wet.

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WW9B (CH8)

B6C 20-30 mm (horizontal section)

Thin Section - Coarse (10-20 mm) aggregates are composed of porphyritic fine-grained granite (weakly recrystallized) and fine to medium-grained granite. Fine (5-8 mm) aggregates are composed of porphyritic fine-grained granite, fine to medium-grained granite and occasional quartz microdiorite. Sand is composed of granitic rock fragments, quartz and feldspar crystals (some strained). About 40% of the cement paste is carbonated, apparent near cracks in the cement paste, ring cracks surrounding aggregate particles and the edge of the slide. The cement paste is well hydrated (W/C = 0.55). Cracks (1 mm) are present in the cement paste, along aggregate surface and within an aggregate. Ettringite is occasionally present bordering and infilling air voids. There is no obvious alkali-silica gel present.

Polished Slab - Coarse aggregates are composed of porphyritic fine-grained granite and occasional mafic rock fragments. Fine aggregates are composed of porphyritic fine-grained granite, fine-grained granite and quartz crystals. Sand is composed of granitic and mafic rock fragments, quartz and feldspar crystals. A crack (0.5-1 mm) in the cement paste connects with the surface of an aggregate may contain alkali-silica gel. A few small (c. 0.5 mm) air voids are possibly bordered or completely infilled with ettringite. Grey cement paste when wet.

B6D 65-75 mm (horizontal section)

Thin Section - Coarse (10-20 mm) aggregates are composed of porphyritic fine-grained granite (some weakly recrystallized) and fine to medium-grained granite. Fine (5-8 mm) aggregates are composed of fine-grained granite (some porphyritic) and fine to medium-grained granite. Sand is composed of granitic rock fragments, quartz and feldspar crystals. Some feldspars show granophyric texture. About 20% of the cement paste is carbonated mainly near cracks and along the edge of the slide. The cement paste is well hydrated (W/C = 0.55). Cracks (1 mm) are present in the cement paste and ring cracks surrounding aggregate particles, and are resin-infilled. A few minor (<0.05 mm) cracks are present in the cement paste. Ettringite completely infills a few small (c. 0.2 mm) air voids and internally borders larger (c. 2 mm) ones. There is no obvious alkali-silica gel present. Minor steel fibres are present in the cement paste.

Polished Slab - Coarse aggregates are composed of porphyritic fine-grained granite and fine to medium-grained granite. Fine aggregates are composed of porphyritic fine-grained granite, fine-grained granite and mafic rock fragments. Sand is composed of granitic rock fragments, quartz and feldspar crystals. A crack (1 mm) in the cement paste connects with an aggregate surface may be infilled with possible ettringite. A few air voids (1-2 mm) are bordered with possible ettringite. Grey cement paste when wet.

B7B 300-310 mm (horizontal section)

Thin Section - Coarse (10-20 mm) and fine (5-8 mm) aggregates are composed of fine to medium-grained granite and porphyritic fine-grained granite (some weakly recrystallized). Coarse aggregates also composed of quartz microdiorite. Sand is composed of granitic rock fragments, quartz and feldspar crystals. Minor amounts of the cement paste are carbonated mainly near air voids, cracks and the edge of the slide. The cement paste is well hydrated (W/C = 0.55). Occasional minor (<0.1 mm) cracks are present in the cement paste and are unfilled. Ettringite borders and completely infills small (c. 0.2 mm) air voids and occasionally borders larger (c. 2 mm) ones. There is no obvious alkali-silica gel present.

Polished Slab - Coarse aggregates are composed of porphyritic fine-grained granite, fine to medium-grained granite and foliated mafic rock fragments. Fine aggregates are composed of porphyritic fine-grained granite, fine to medium-grained granite and mafic rock fragments. Sand is composed of granitic and mafic rock fragments, quartz and feldspar crystals. Large (1-2 mm) air voids are bordered and smaller (0.2-0.5 mm) ones are completely infilled with possible ettringite. Minor (<0.1 mm) cracks in the cement paste connect with aggregate surfaces and some may be infilled with ettringite. Grey cement paste when wet.

B6A 0-60 mm (vertical section)

Thin Section - Coarse (10-20 mm) and fine (5-8 mm) aggregates are composed of fine to medium-grained granite and porphyritic fine-grained granite (some weakly recrystallized). Fine aggregates also composed of fine-grained granite with tuffisite veins. Sand is composed of granitic rock fragments, quartz and feldspar crystals. Some feldspars show granophyric texture. About 30% of the cement paste is carbonated mainly near cracks and the top of the slide. The cement paste is well hydrated (W/C = 0.55). An unfilled-crack is present in the cement paste connects with and passes through a few fine aggregates. Ettringite borders a few air voids and completely infills smaller (c. 0.2 mm) ones. There is no obvious alkali-silica gel present.

Polished Slab - Coarse aggregates are composed of porphyritic fine-grained granite and fine to medium-grained granite. Fine aggregates are composed of porphyritic fine-grained granite, fine-grained granite and occasional mafic rock fragments. Sand is composed of granitic and mafic rock fragments, quartz and feldspar crystals. Large (1-2 mm) air voids are bordered and smaller (0.2-0.5 mm) ones are completely infilled with possible ettringite. Cracks in the cement paste and ring cracks surrounding aggregate particles appear to be infilled with ettringite. Grey cement paste when wet.

B6B 75-135 mm (vertical section)

Thin Section - Coarse (10-20 mm) and fine (5-8 mm) aggregates are composed of fine to medium-grained granite and porphyritic fine-grained granite (some weakly recrystallized). Coarse aggregates may also be composed of porphyritic fine-grained granite particles hosting occasional tuffisite veins. Sand is composed of granitic rock fragments, quartz and feldspar crystals. Some feldspars show granophyric texture. About 60% of the cement paste is carbonated throughout the slide, and especially surrounding air voids and cracks. The cement paste is well hydrated (W/C = 0.55). A few minor (<0.05 mm) cracks are present in the cement paste and within aggregates. Ettringite occasionally borders air voids and completely infills smaller (c. 0.2 mm) ones, and occasionally borders ring cracks surrounding aggregate particles. Layered alkali-silica gel is present in trace amounts on the internal borders of an air void.

Polished Slab - Coarse aggregates are composed of porphyritic fine-grained granite and occasional fine to medium-grained granite. Fine aggregates are composed of porphyritic

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fine-grained granite, occasional mafic rock fragments and quartz crystals. Sand is composed of granitic and occasional mafic rock fragments, quartz and feldspar crystals. Some small (0.2-0.5 mm) air voids are bordered with possible ettringite while larger (1-2 mm) ones are unfilled. Ring cracks surrounding aggregate particles and cracks in the cement paste are concentrated locally and may be infilled with ettringite. Grey cement paste when wet.

B7A 240-300 mm (vertical section)

Thin Section - Coarse (10-20 mm) aggregates are composed of porphyritic fine-grained granite (some weakly recrystallized), fine to medium-grained granite and a single fragment of cataclasite with minor strained quartz. Fine (5-8 mm) aggregates are composed of porphyritic fine-grained granite, fine to medium-grained granite, and porphyritic fine-grained granite with tuffisite veins. Sand is composed of granitic rock fragments, quartz and feldspar crystals. About 30% of the cement paste is carbonated. The cement paste is well hydrated (W/C = 0.55). Some minor (<0.05 mm) cracks in the cement paste connect with aggregates. Ettringite borders air voids, and occasionally completely infills smaller (c. 0.2 mm) ones and cracks. Trace amounts of alkali-silica gel may be present in a crack near one aggregate particle.

Polished Slab - Coarse aggregates are composed of fine to medium-grained granite and porphyritic fine-grained granite. Fine aggregates are composed of porphyritic fine-grained granite and granitic rock fragments. Sand is composed of granitic and mafic rock fragments, quartz and feldspar crystals. A few small (0.2-0.5 mm) air voids are completely infilled with possible ettringite. Minor (<0.1 mm) cracks in the cement paste and ring cracks surrounding aggregate particles are infilled with possible ettringite. Some alkali-silica gel may be present locally near ring cracks, cracks in the cement paste and within aggregates. Grey cement paste when wet.

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WW34 (CH5)

A8C 20-30 mm (horizontal section)

Thin Section - Coarse (10-20 mm) aggregates are composed of porphyritic fine-grained granite. Fine (5-8 mm) aggregates are composed of porphyritic fine-grained granite, fine-grained granite with some strained quartz, and weakly recrystallized medium-grained granite. Sand is composed of granitic rock fragments, quartz and feldspar crystals (some strained). Feldspar is microcline plus some granophyric and perthitic textures. About 60% of the cement paste is carbonated, apparent especially near cracks and in ring cracks surrounding aggregate particles. The cement paste is very well hydrated except scattered grains of belite are visible (W/C = 0.6). Cracks (1 mm) are present commonly in the cement paste and within aggregates, occasionally as ring cracks surrounding aggregate particles. These cracks are resin-infilled. Air voids are resin-infilled. There is no obvious alkali-silica gel and ettringite present.

Polished Slab - Coarse aggregates are composed of porphyritic fine-grained granite and fine to medium-grained granite. Fine aggregates are composed of porphyritic fine-grained granite. Sand is composed of granitic rock fragments, quartz and feldspar crystals. A few major cracks (0.5-1 mm) in the cement paste, which connect with ring cracks surrounding aggregate particles and occasionally pass through aggregates, may contain alkali-silica gel locally. A few minor (<0.1 mm) cracks in the cement paste connect with aggregates. Some air voids are internally bordered with possible ettringite. Light grey spotted white cement paste when wet.

A8D 65-75 mm (horizontal section)

Thin Section - Coarse (10-20 mm) aggregates are composed of porphyritic fine-grained granite with some strained quartz, weakly recrystallized porphyritic fine-grained granite and inequigranular altered/strained fine to medium-grained granite. Fine (5-8 mm) aggregates are composed of porphyritic fine-grained granite (some weakly recrystallized). Sand is composed of granitic rock fragments (one moderately decomposed), quartz and feldspar crystals. Feldspar is microcline plus some granophyric textures. About 10% of the cement paste is carbonated mainly near cracks and along the edge of the slide. The cement paste is very well hydrated (W/C = 0.6). A few minor (<0.1 mm) cracks are present in the cement paste and within aggregates, more commonly among the inequigranular altered/strained fine to medium-grained granite. A few ring cracks surrounding aggregate particles are infilled with ettringite, the cracks then pass through the cement paste, and connect with other aggregates. Ettringite borders large (c. 1 mm) air voids and completely infilled smaller (c. 0.2 mm) ones, and infilled some minor cracks. There is no obvious alkali-silica gel present.

Polished Slab - Coarse and fine aggregates are composed of porphyritic fine-grained granite and fine to medium-grained granite. Sand is composed of granitic rock fragments, quartz and feldspar crystals. Many air voids are commonly internally bordered with possible ettringite. Some possible alkali-silica gel may be present as patches locally. Ring cracks surrounding aggregate particles may be bordered or infilled with ettringite. Light grey cement paste when wet.

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A8E 135-145 mm (horizontal section)

Thin Section - Coarse (10-20 mm) aggregates are composed of fine-grained granite with altered feldspar and minor strained quartz; fine to medium-grained granite with altered feldspar and strained quartz and feldspar, porphyritic fine-grained granite with altered feldspar and strained quartz, and quartz microdiorite. Fine (5-8 mm) aggregates are composed of fine to medium-grained granite with altered feldspar and strained quartz and feldspar, porphyritic fine-grained granite with altered feldspar. Sand is composed of granitic rock fragments, quartz and feldspar crystals. Minor amounts of the cement paste are carbonated mainly along the edge of the slide. The cement paste is very well hydrated (W/C = 0.6). Some minor (<0.05 mm) cracks in the cement paste and ring cracks surrounding aggregate particles, some of which are infilled with ettringite (mainly in the altered/strained fine to medium-grained granite). Ettringite borders and completely infills some air voids, along a ring crack and connects other aggregates, and in some minor (<0.05 mm) cracks. There is no obvious alkali-silica gel present.

Polished Slab - Coarse aggregates are composed of porphyritic fine-grained granite, fine to medium-grained granite and occasional mafic rock fragments. Fine aggregates are composed of porphyritic fine-grained granite and granitic rock fragments. Sand is composed of granitic rock fragments, quartz and feldspar crystals. Numerous minor (<0.1 mm) cracks in the cement paste and a few cracks within aggregates. Some cracks in the cement paste may be infilled with ettringite. Ring cracks surrounding aggregate particles are common and may be infilled with ettringite. Air voids are internally bordered with possible ettringite. Trace amounts of alkali-silica gel may be present along a few minor (<0.1 mm) cracks in the cement paste. Light grey cement paste when wet.

A9B 240-250 mm (horizontal section)

Thin Section - Coarse (10-20 mm) aggregates are composed of weakly recrystallized porphyritic fine-grained granite with altered feldspar and severe strained quartz and with ring cracks infilled with ettringite, porphyritic fine-grained granite with altered feldspar and strained quartz, fine to medium-grained granite with altered feldspar and strained quartz and with ring crack infilled with ettringite. Fine (5-8 mm) aggregates are composed of porphyritic fine-grained granite with altered feldspar and minor ring crack, weakly recrystallized porphyritic fine-grained granite with altered feldspar and strained quartz and with ring crack infilled with ettringite, porphyritic fine-grained granite with altered feldspar and strained quartz with ring crack infilled with ettringite. Sand is composed of granitic rock fragments with altered feldspar and strained quartz and feldspar, quartz and feldspar crystals. About 50% of the cement paste is carbonated. The cement paste is very well hydrated (W/C = 0.6). Some minor (<0.1 mm) cracks are present in the cement paste (some connect with aggregates) and within aggregates. Ettringite borders some air voids and in some minor (<0.1 mm) cracks. Trace layered alkali-silica gel, which has been partly desiccated, is present on the margins of some aggregate particles.

Polished Slab - Coarse aggregates are composed of porphyritic fine-grained granite and fine to medium-grained granite. Fine aggregates are composed of porphyritic fine-grained granite and granitic rock fragments. Sand is composed of granitic rock fragments, quartz and feldspar crystals. Ring cracks surrounding aggregate particles are common and possibly infilled with ettringite. A few cracks within aggregates are unfilled. A few air voids are present and some

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are internally bordered with possible ettringite. Trace amounts of possible alkali-silica gel may be present surrounding a fine aggregate. Light grey cement paste when wet.

A0B 1060-1080 mm (horizontal section)

Thin Section - Coarse (10-20 mm) aggregates are composed of weakly recrystallized porphyritic fine-grained granite with altered feldspar and severe strained quartz and with ring crack infilled with ettringite, porphyritic fine-grained granite with altered feldspar and strained quartz, fine to medium-grained granite with altered feldspar and strained quartz and with ring crack infilled with ettringite. Fine (5-8 mm) aggregates are composed of porphyritic fine-grained granite with altered feldspar and ring crack, weakly recrystallized porphyritic fine-grained granite with altered feldspar and strained quartz and with ring crack infilled with ettringite, porphyritic fine-grained granite with altered feldspar and strained quartz with ring crack infilled with ettringite. Sand is composed of granitic rock fragments with altered feldspar and strained quartz and feldspar, quartz and feldspar crystals. About 50% of the cement paste is carbonated. The cement paste is very well hydrated (W/C = 0.6). A few minor (c. 0.1 mm) cracks are present in the cement paste (some connect with aggregates) and within aggregates. Ettringite borders and completely infills some air voids (c. 0.3 mm) and completely infilled a few minor (c. 0.1 mm) cracks. Thin layers of alkali-silica gel line some air voids and have been clearly distrupted by later growth of ettringite.

Polished Slab - Coarse aggregates are composed of porphyritic fine-grained granite and altered fine to medium-grained granite. Fine aggregates are composed of porphyritic fine-grained granite and granitic rock fragments. Sand is composed of granitic rock fragments, quartz and feldspar crystals. A few cracks in the cement paste and ring cracks surrounding aggregate particles may be infilled with ettringite. Many air voids are present, large (c. 1 mm) ones are bordered and smaller (c. 0.2 mm) ones are completely infilled with possible ettringite. Dark grey cement paste when wet.

A8A 0-60 mm (vertical section)

Thin Section - Coarse (10-20 mm) aggregates are composed of fine to medium-grained granite with altered feldspar, porphyritic fine-grained granite with altered feldspar, weakly recrystallized porphyritic fine-grained granite with altered feldspar, porphyritic fine-grained granite with altered feldspar and strained quartz, and quartz microdiorite. Fine (5-8 mm) aggregates are composed of fine to medium-grained granite with altered feldspar, fine grained granite with some strained quartz and feldspar, weakly recrystallized porphyritic fine-grained granite with altered feldspar, fine-grained granite with ring crack infilled with ettringite, weakly recrystallized porphyritic fine-grained granite with altered feldspar and minor strained quartz. Sand is composed of granitic rock fragments, quartz and feldspar crystals. Some feldspars show granophyric texture. About 25% of the cement paste is carbonated near the bottom of the slide. The cement paste is very well hydrated (W/C = 0.6). Occasional minor (<0.05 mm) cracks are present in the cement paste and within aggregates. Ettringite borders many large (0.5-1 mm) air voids and completely infilled smaller (c. 0.2 mm) ones, and along occasional ring cracks surrounding aggregate particles. There is no obvious alkali-silica gel present. Minor steel fibres are present in the cement paste.

Polished Slab - Coarse aggregates are rare and are composed of altered fine to medium-grained granite. Fine aggregates are composed of porphyritic fine-grained granite and

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granitic rock fragments. Sand is composed of granitic rock fragments, quartz and feldspar crystals. Some minor (<0.1 mm) cracks in the cement paste are common especially in two localities, and may contain alkali-silica gel. Alkali-silica gel may also be present near the altered fine to medium-grained granite. Air voids are internally bordered, some are completely infilled, with possible ettringite. Light grey locally pink cement paste when wet.

A8B 75-135 mm (vertical section)

Thin Section - Coarse (10-20 mm) aggregates are composed of porphyritic fine-grained granite with altered feldspar, fine to medium-grained granite with altered feldspar and with ring crack infilled with ettringite, weakly recrystallized porphyritic fine-grained granite with altered feldspar, porphyritic fine-grained granite with altered feldspar and with partial ring crack infilled with ettringite. Fine (5-8 mm) aggregates are composed of porphyritic fine-grained granite with altered feldspar, and fine to medium-grained granite with altered feldspar. Sand is composed of granitic rock fragments, quartz and feldspar crystals. About 60% of the cement paste is carbonated, but not near cracks nor along the edge of the slide. The cement paste is very well hydrated (W/C = 0.55). A few minor (<0.05 mm) cracks are present in the cement paste and within aggregates. A ring crack surrounding aggregate particle infilled with ettringite, passes through the cement paste, connects with other aggregates. Ettringite borders many air voids and commonly infills ring cracks surrounding aggregate particles. There are minor amounts of desiccated alkali-silica gel present in cracks.

Polished Slab - Coarse aggregates are composed of porphyritic fine-grained granite and fine to medium-grained. Fine aggregates are composed of porphyritic fine-grained granite, granitic and mafic rock fragments. Sand is composed of granitic rock fragments, quartz and feldspar crystals. Ring cracks surrounding aggregate particles and cracks in the cement paste (which connect with aggregates) are localised and may contain alkali-silica gel and ettringite. Some air voids are internally bordered or completely infilled with possible ettringite. Light grey cement paste when wet.

A9A 180-240 mm (vertical section)

Thin Section - Coarse (10-20 mm) and fine (5-8 mm) aggregates are composed of porphyritic fine-grained granite (weakly recrystallized) and fine to medium-grained granite. Sand is composed of granitic rock fragments, quartz and feldspar crystals. About 20% of the cement paste is carbonated scattered throughout the slide. The cement paste is very well hydrated (W/C = 0.6). Ring cracks surrounding aggregate particles and cracks in the cement paste are common and are commonly bordered or completely infilled with ettringite. Air voids are internally bordered, and many are completely infilled, with ettringite. There are minor amounts of desiccated alkali-silica gel in cracks. Minor steel fibres are present in the cement paste.

Polished Slab - Coarse aggregates are composed of porphyritic fine-grained granite and fine to medium-grained granite. Fine aggregates are composed of porphyritic fine-grained granite and granitic rock fragments. Sand is composed of granitic rock fragments, quartz and feldspar crystals. Cracks within some aggregates are unfilled. Air voids are internally bordered, occasionally completely infilled, with possible ettringite. Light grey cement paste when wet.

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A0A 1000-1060 mm (vertical section)

Thin Section - Coarse (10-20 mm) and fine (5-8 mm) aggregates are composed of porphyritic fine-grained granite (weakly recrystallized) and fine to medium-grained granite. Sand is composed of granitic rock fragments, quartz and feldspar crystals. Some feldspars show granophyric texture. About 60% of the cement paste is carbonated scattered throughout the slide. The cement paste is very well hydrated (W/C = 0.6). Cracks in the cement paste and ring cracks surrounding aggregate particles are common and are commonly bordered or infilled with ettringite. Air voids are internally bordered, commonly completely infilled, with ettringite. There are minor amounts of desiccated alkali-silica gel in cracks. Minor steel fibres are present in the cement paste.

Polished Slab - Coarse aggregates are composed of porphyritic fine-grained granite and fine to medium-grained granite. Fine aggregates are composed of porphyritic fine-grained granite and granitic rock fragments. Sand is composed of granitic rock fragments, quartz and feldspar crystals. Minor amount of possible alkali-silica gel may be present near a couple of aggregates. Some air voids are internally bordered, and some smaller ones are completely infilled, with possible ettringite. Dark grey cement paste when wet.

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WW35 (CH1)

A1D 20-30 mm (horizontal section)

Thin Section - Coarse (10-20 mm) and fine (5-8 mm) aggregate are composed of porphyritic fine-grained granite (some weakly recrystallized) and fine to medium-grained granite. Sand is composed of granitic rock fragments, quartz and feldspar crystals. About 5% of the cement paste is carbonated near cracks, air voids and the edge of the slide. The cement paste is well hydrated (W/C = 0.5). A few minor (<0.1 mm) cracks in the cement paste and some ring cracks surrounding aggregate particles are infilled with ettringite. Air voids are commonly internally bordered, some smaller (c. 0.2 mm) ones are completely infilled, with ettringite. There is no obvious alkali-silica gel present.

Polished Slab - Coarse aggregates are composed of fine to medium-grained granite and porphyritic fine-grained granite. Fine aggregates are rare and are composed of granitic rock fragments. Sand is composed of granitic and mafic rock fragments, quartz and feldspar crystals. A major crack (1-2 mm) in the cement paste, which connects with ring cracks surrounding aggregate particles and passes through aggregates, and occasional ring cracks surrounding aggregate particles may contain alkali-silica gel locally. Air voids are commonly internally bordered with possible ettringite. Light grey cement paste when wet.

A1E 65-75 mm (horizontal section)

Thin Section - Coarse (10-20 mm) aggregates are composed of porphyritic fine-grained granite (some weakly recrystallized). Fine (5-8 mm) aggregates are composed of porphyritic fine-grained granite (some weakly recrystallized), fine to medium-grained granite and quartz microdiorite. Sand is composed of granitic rock fragments, quartz and feldspar crystals. About 10% of the cement paste is carbonated near cracks and the edge of the slide. The cement paste is well hydrated (W/C = 0.5). Many minor (<0.1 mm) cracks in the cement paste (some connect with ring cracks surrounding aggregate particles) and ring cracks surrounding aggregate particles are completely infilled with ettringite. Air voids are commonly internally bordered, smaller (c. 0.2 mm) ones are completely infilled, with ettringite. There is no obvious alkali-silica gel present.

Polished Slab - Coarse aggregates are composed of porphyritic fine-grained granite. Fine aggregates are composed of granitic and mafic rock fragments and porphyritic fine-grained granite. Sand is composed of granitic rock fragments, quartz and feldspar crystals. Many minor (0.1-0.4 mm) cracks in the cement paste and some ring cracks surrounding aggregate particles may contain ettringite. A couple of major cracks (0.5 mm) in the cement paste, which connect with ring cracks surrounding aggregate particles, may contain some alkali-silica gel. A few air voids are completely infilled or internally bordered with possible ettringite. Light grey cement paste when wet.

A1F 135-145 mm (horizontal section)

Thin Section - Coarse (10-20 mm) aggregates are composed of porphyritic fine-grained granite (some weakly recrystallized) and fine to medium-grained granite. Fine (5-8 mm) aggregates are composed of porphyritic fine-grained granite (some weakly recrystallized), occasional tuffisite vein within aggregate and feldspar crystals. Sand is composed of

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granitic rock fragments, quartz and feldspar crystals. About 10% of the cement paste is carbonated near the edge of the slide and occasional near ring cracks surrounding aggregate particles. The cement paste is well hydrated (W/C = 0.5). Abundant minor (c. 0.1 mm) cracks in the cement paste (some connect with ring cracks) and ring cracks surrounding aggregate particles are commonly completely infilled with ettringite. Air voids are commonly completely infilled with ettringite. Small amounts of layered alkali-silica gel are present along some ring cracks and cracks in the cement paste which emanating from the tuffisite vein. Minor steel fibres are present in the cement paste.

Polished Slab - Coarse aggregates are composed of fine to medium-grained granite and porphyritic fine-grained granite. Fine aggregates are composed of granitic rock fragments and porphyritic fine-grained granite. Sand is composed of granitic and occasional mafic rock fragments, quartz and feldspar crystals. Many minor (<0.1 mm) cracks in the cement paste and ring cracks surrounding aggregate particles are commonly infilled with possible ettringite. A few minor (<0.1 mm) cracks in the cement paste and occasional ring cracks surrounding aggregate particles may also contain alkali-silica gel. Occasional air voids are internally bordered with possible ettringite. Light grey cement paste when wet.

A1G 240-250 mm (horizontal section)

Thin Section - Coarse (10-20 mm) aggregates are composed of porphyritic fine-grained granite (some weakly recrystallized). Fine (5-8 mm) aggregates are composed of porphyritic fine-grained granite (some weakly recrystallized) and fine to medium-grained granite. Sand is composed of granitic rock fragments, quartz and feldspar crystals. About 5% of the cement paste is carbonated near the edge of the slide. The cement paste is fairly well hydrated (W/C = 0.5). Abundant minor (<0.1 mm) cracks in the cement paste (some connect with ring cracks surrounding aggregate particles) and ring cracks surrounding aggregate particles are commonly completely infilled with ettringite and layered alkali-silica gel. Air voids are commonly completely infilled with ettringite. Small amounts of alkali-silica gel are present in a crack within a quartz crystal.

Polished Slab - Coarse aggregates are composed of porphyritic fine-grained granite. Fine aggregates are composed of granitic rock fragments and porphyritic fine-grained granite. Sand is composed of granitic rock fragments, quartz and feldspar crystals. Some minor (<0.1 mm) cracks in the cement paste and a few ring cracks surrounding aggregate particles may be infilled with ettringite or alkali-silica gel. Large (c. 1 mm) air voids are common and are internally bordered with possible ettringite. Light grey cement paste when wet.

A2B 1060-1070 mm (horizontal section)

Thin Section - Coarse (10-20 mm) aggregates are composed of porphyritic fine-grained granite (some weakly recrystallized) and occasional fine to medium-grained granite. Fine (5-8 mm) aggregates are composed of porphyritic fine-grained granite (some weakly recrystallized), fine to medium-grained granite and fine-grained granite. Sand is composed of granitic rock fragments, quartz and feldspar crystals. About 10% of the cement paste is carbonated near the edge of the slide. The cement paste is fairly well hydrated (W/C = 0.5). Many minor (c. 0.1 mm) cracks in the cement paste (some connect with ring cracks surrounding aggregate particles) and ring cracks surrounding aggregate particles are commonly completely infilled with ettringite. Air voids are common and are internally

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bordered or completely infilled with ettringite. There is minor layered alkali-silica gel bordering the internal margin of an air void. Minor steel fibres are present in the cement paste.

Polished Slab - Coarse aggregates are composed of fine to medium-grained granite and porphyritic fine-grained granite. Fine aggregates are composed of granitic rock fragments. Sand is composed of granitic rock fragments, quartz and feldspar crystals. Some minor (<0.1 mm) cracks in the cement paste and ring cracks surrounding aggregate particles may be infilled with abundant ettringite. Large (c. 2 mm) air voids are common and are internally bordered, smaller (c. 0.2 mm) ones are completely infilled, with possible ettringite. Light grey cement paste when wet.

A3B 1990-2000 mm (horizontal section)

Thin Section - Coarse (10-20 mm) aggregates are composed of porphyritic fine-grained granite (some weakly recrystallized). Fine (5-8 mm) aggregates are composed of porphyritic fine-grained granite (some weakly recrystallized) and fine to medium-grained granite. Sand is composed of granitic rock fragments, quartz and feldspar crystals. About 5% of the cement paste is carbonated near the edge of the slide. The cement paste is fairly well hydrated (W/C = 0.5). Some minor (<0.1 mm) cracks in the cement paste, many ring cracks surrounding aggregate particles and air voids are completely infilled with ettringite. Layered alkali-silica gel is present bordering the internal margins of an air void. Minor steel fibres are present in the cement paste.

Polished Slab - Coarse aggregates are composed of porphyritic fine-grained granite and occasional fine to medium-grained granite. Fine aggregates are composed of granitic rock fragments and porphyritic fine-grained granite. Sand is composed of granitic rock fragments, quartz and feldspar crystals. Abundant minor (<0.1 mm) cracks in the cement paste and ring cracks surrounding aggregate particles (and occasional cracks within aggregates) are commonly infilled with possible ettringite. Air voids are commonly internally bordered, some smaller (c. 0.3 mm) ones are completely infilled, with possible ettringite. Grey cement paste when wet.

A1A 0-60 mm (vertical section)

Thin Section - Coarse (10-20 mm) aggregates are composed of porphyritic fine-grained granite (some weakly recrystallized) and fine to medium-grained granite. Fine (5-8 mm) aggregates are composed of porphyritic fine-grained granite (some weakly recrystallized), fine to medium-grained granite and fine-grained granite. Sand is composed of granitic rock fragments, quartz and feldspar crystals. About 5% of the cement paste is carbonated near the top of the slide. The cement paste is well hydrated (W/C = 0.5). Many minor (<0.1 mm) cracks in the cement paste and ring cracks surrounding aggregate particles are commonly completely infilled with ettringite. Air voids are common and are internally bordered, some are completely infilled, with ettringite. Layered alkali-silica gel is present infilling some cracks.

Polished Slab - Coarse aggregates are composed of fine to medium-grained granite and porphyritic fine-grained granite. Fine aggregates are composed of granitic rock fragments. Sand is composed of granitic rock fragments, quartz and feldspar crystals. Some ring cracks

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surrounding aggregate particles and a few minor (<0.1 mm) cracks in the cement paste may be infilled with ettringite. Localised minor (<0.1 mm) cracks in the cement paste may also contain alkali-silica gel. A few air voids are completely infilled with possible ettringite. Light grey cement paste when wet.

A1B 75-135 mm (vertical section)

Thin Section - Coarse (10-20 mm) aggregates are composed of porphyritic fine-grained granite (some weakly recrystallized). Fine (5-8 mm) aggregates are composed of porphyritic fine-grained granite (some weakly recrystallized) and fine to medium-grained granite. Sand is composed of granitic rock fragments, quartz and feldspar crystals. About 20% of the cement paste is carbonated near major cracks (1 mm) and some ring cracks surrounding aggregate particles. The cement paste is well hydrated (W/C = 0.45). Abundant minor (<0.1 mm) cracks in the cement paste and ring cracks surrounding aggregate particles are commonly bordered, some are completely infilled, with ettringite. A few air voids are internally bordered or completely infilled with ettringite. Layered alkali-silica gel is present in some ring cracks.

Polished Slab - Coarse aggregates are composed of fine to medium-grained granite and porphyritic fine-grained granite. Fine aggregates are composed of granitic rock fragments. Sand is composed of granitic rock fragments, quartz and feldspar crystals. A few ring cracks surrounding aggregate particles may be infilled with ettringite. Many minor (<0.1 mm) cracks in the cement paste may contain alkali-silica gel. A major crack (1 mm) in the cement paste, which connects with ring crack, may contain trace amounts of alkali-silica gel. Occasional small (<0.2 mm) air voids are completely infilled with possible ettringite. Light grey cement paste when wet.

A1C 180-240 mm (vertical section)

Thin Section - Coarse (10-20 mm) and fine (5-8 mm) aggregates are composed of porphyritic fine-grained granite (some weakly recrystallized) and fine to medium-grained granite. Sand is composed of granitic rock fragments, quartz and feldspar crystals. Very minor amount of the cement paste is carbonated. The cement paste is well hydrated (W/C = 0.5). Many minor (<0.1 mm) cracks in the cement paste and ring cracks surrounding aggregate particles are commonly completely infilled with ettringite. Air voids are common and are commonly completely infilled with ettringite. Layered alkali-silica gel is present bordering an air void and along part of a ring crack surrounding aggregate particles. Minor steel fibres are present in the cement paste.

Polished Slab - Coarse aggregates are composed of fine to medium-grained granite and porphyritic fine-grained granite. Fine aggregates are composed of granitic rock fragments and porphyritic fine-grained granite. Sand is composed of granitic rock fragments, quartz and feldspar crystals. Some minor (<0.1 mm) cracks in the cement paste and ring cracks surrounding aggregate particles may contain alkali-silica gel and infilled with ettringite. A major crack (0.5 mm) in the cement paste, which connects with ring crack surrounding aggregate particle, is partly infilled with possible ettringite and alkali-silica gel. A very large (9 mm) air void is internally bordered with possible ettringite. Light grey cement paste when wet.

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A2A 1000-1060 mm (vertical section)

Thin Section - Coarse (10-20 mm) and fine (5-8 mm) aggregates are composed of porphyritic fine-grained granite (some weakly recrystallized) and fine to medium-grained granite. Sand is composed of granitic rock fragments, quartz and feldspar crystals. Very minor amount of the cement paste is carbonated near the bottom of the slide. The cement paste is well hydrated (W/C = 0.5). Many minor (<0.1 mm) cracks in the cement paste (some connect with ring cracks) and ring cracks surrounding aggregate particles are commonly completely infilled with ettringite. Air voids are common and are commonly completely infilled with ettringite. There is no obvious alkali-silica gel present. Minor steel fibres are present in the cement paste.

Polished Slab - Coarse aggregates are composed of fine to medium-grained granite and porphyritic fine-grained granite. Fine aggregates are composed of granitic rock fragments and porphyritic fine-grained granite. Sand is composed of granitic rock fragments, quartz and feldspar crystals. Some ring cracks surrounding aggregate particles may be infilled with ettringite. A few minor cracks in the cement paste may contain alkali-silica gel. Large (c. 1 mm) air voids are commonly internally bordered, smaller (c. 0.2 mm) ones are completely infilled, with possible ettringite. Light grey cement paste when wet.

A3A 1930-1990 mm (vertical section)

Thin Section - Coarse (10-20 mm) aggregates are composed of porphyritic fine-grained granite (some weakly recrystallized), fine to medium-grained granite and fine-grained granite. Fine (5-8 mm) aggregates are composed of porphyritic fine-grained granite (some weakly recrystallized) and fine to medium-grained granite. Sand is composed of granitic rock fragments, quartz and feldspar crystals. About 30% of the cement paste is carbonated scattered throughout the slide. The cement paste is fairly well hydrated (W/C = 0.5). Many minor (<0.1 mm) cracks in the cement paste (some connect with ring cracks surrounding aggregate particles) and ring cracks surrounding aggregate particles are commonly completely infilled with ettringite. Air voids are common and are commonly completely infilled with ettringite. Layered alkali-silica gel is present in some cracks. Minor steel fibres are present in the cement paste.

Polished Slab - Coarse aggregates are composed of fine to medium-grained granite and porphyritic fine-grained granite. Fine aggregates are composed of granitic rock fragments and porphyritic fine-grained granite. Sand is composed of granitic rock fragments, quartz and feldspar crystals. Some minor (<0.1 mm) cracks in the cement paste and many ring cracks surrounding aggregate particles may be infilled with ettringite. Occasional minor (<0.1 mm) cracks in the cement paste may also contain alkali-silica gel. Large (c. 1 mm) air voids are internally bordered, smaller (c. 0.2 mm) ones are completely infilled, with possible ettringite. Light grey cement paste when wet.

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WW35 (CH2)

A4D 20-30 mm (horizontal section)

Thin Section - Coarse (10-20 mm) aggregates are composed of porphyritic fine-grained granite (some weakly recrystallized). Fine (5-8 mm) aggregates are composed of porphyritic fine-grained granite (weakly recrystallized), occasional fine to medium-grained granite. Sand is composed of granitic rock fragments, quartz and feldspar crystals. About 10% of the cement paste is carbonated near cracks in the cement paste and ring cracks surrounding aggregate particles, air voids and the edge of the slide. The cement paste is well hydrated (W/C = 0.45). Some minor (<0.1 mm) cracks in the cement paste and abundant ring cracks surrounding aggregate particles are present, and majority of them are infilled with ettringite. Occasional large (c. 3 mm) air voids are internally bordered with ettringite. There is no obvious alkali-silica gel present. Minor steel fibres are present in the cement paste.

Polished Slab - Coarse aggregates are composed of porphyritic fine-grained granite. Fine aggregates are composed of porphytitic fine-grained granite and granitic rock fragments. Sand is composed of granitic rock fragments, quartz and feldspar crystals. A few cracks (<0.1 mm and 0.2 mm) in the cement paste, some may contain alkali-silica gel. Some ring cracks surrounding aggregate particles may be infilled with ettringite. Occasional air voids (c. 1 mm) are internally bordered with possible ettringite. Light grey cement paste when wet.

A4E 135-145 mm (horizontal section)

Thin Section - Coarse (10-20 mm) and fine (5-8 mm) aggregates are composed of porphyritic fine-grained granite (some weakly recrystallized) and fine to medium-grained granite. Sand is composed of granitic rock fragments, quartz and feldspar crystals. About 5% of the cement paste is carbonated near ring cracks surrounding aggregate particles and the edge of the slide. The cement paste is well hydrated (W/C = 0.45). Cracks in the cement paste and ring cracks surrounding aggregate particles are very common and are infilled with abundant ettringite. Some air voids are internally bordered, smaller (c. 0.1 mm) ones are completely infilled, with ettringite. Layered alkali-silica gel is present along some ring cracks, cracks in the cement paste and cracks within a few aggregates.

Polished Slab - Coarse aggregates are composed of porphyritic fine-grained granite and fine to medium-grained granite. Fine aggregates are composed of fine to medium-grained granite and granitic rock fragments. Sand is composed of granitic rock fragments, quartz and feldspar crystals. Many minor (<0.1 mm) cracks in the cement paste (some connect with ring cracks surrounding aggregate particles) and a few ring cracks surrounding aggregate particles are possibly infilled with ettringite, some of them may also contain alkali-silica gel. A few air voids are internally bordered with possible ettringite. Light grey cement paste when wet.

A4F 240-250 mm (horizontal section)

Thin Section - Coarse (10-20 mm) and fine (5-8 mm) aggregates are composed of porphyritic fine-grained granite (some weakly recrystallized) and fine to medium-grained granite. Sand is composed of granitic rock fragments, quartz and feldspar crystals. Occasional feldspars show granophyric texture. About 5% of the cement paste is carbonated near the edge of the slide. The cement paste is fairly well hydrated (W/C = 0.5). Cracks (<0.2 mm) in the cement paste and ring cracks surrounding aggregate particles are abundant and are commonly infilled with ettringite. Cracks in the cement paste commonly connect with ring cracks surrounding aggregate particles. Occasioinal large (c. 2 mm) air voids are internally bordered, smaller (c. 0.2 mm) ones are completely infilled, with ettringite. Layered alkali-silica gel is present along some ring cracks surrounding aggregate particles and cracks within aggregates.

Polished Slab - Coarse aggregates are composed of porphyritic fine-grained granite and fine to medium-grained granite. Fine aggregates are composed of porphyritic fine-grained granite and granitic rock fragments. Sand is composed of granitic rock fragments, quartz and feldspar crystals. Abundant minor (<0.1 mm) cracks in the cement paste (commonly connect with ring cracks surrounding aggregate particles) and aggregate surfaces, are possibly infilled with ettringite and may contain alkali-silica gel. Occasional air voids are internally bordered with possible ettringite. Light grey cement paste when wet.

A4A 0-60 mm (vertical section)

Thin Section - Coarse (10-20 mm) and fine (5-8 mm) aggregates are composed of porphyritic fine-grained granite (some weakly recrystallized) and fine to medium-grained granite. Sand is composed of granitic rock fragments, quartz and feldspar crystals. Occasional feldspars show granophyric texture. Very minor amount of the cement paste is carbonated mainly near ring cracks surrounding aggregate particles. The cement paste is fairly well hydrated (W/C = 0.5). Cracks in the cement paste and ring cracks surrounding aggregate particles are abundant and are commonly infilled with ettringite. Cracks in the cement paste commonly connect with ring cracks surrounding aggregate particles. Some air voids are either internally bordered or completely infilled with ettringite. There is no obvious alkali-silica gel present.

Polished Slab - Coarse aggregates are composed of porphyritic fine-grained granite and fine to medium-grained granite. Fine aggregates are composed of porphyritic fine-grained granite and granitic rock fragments. Sand is composed of granitic and occasional mafic rock fragments, quartz and feldspar crystals. A few minor (<0.1 mm) cracks in the cement paste are possibly infilled with ettringite. Ring cracks surrounding aggregate particles are common and may be infilled with ettringite. A major crack (1-2 mm) is resin-infilled. Some air voids (1-2 mm) are internally bordered with possible ettringite. Light grey cement paste when wet.

A4B 75-135 mm (vertical section)

Thin Section - Coarse (10-20 mm) aggregates are composed of porphyritic fine-grained granite (some weakly recrystallized) and fine to medium-grained granite. Fine (5-8 mm) aggregates are composed of porphyritic fine-grained granite (weakly recrystallized), fine to medium-grained granite and occasional granitic fragments. Sand is composed of granitic rock fragments, quartz and feldspar crystals. Occasional feldspars show granophyric texture. About 5% of the cement paste is carbonated near cracks. The cement paste is fairly well hydrated (W/C = 0.5). Minor (<0.1 mm) cracks in the cement paste are common and are infilled with ettringite. Some cracks in the cement paste connect with ring cracks surrounding aggregate particles. Some small (c. 0.2 mm) air voids are completely infilled

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with ettringite. Layered alkali-silica gel, sometimes partly desiccated and cracked, is present in some ring cracks surrounding aggregate particles.

Polished Slab - Coarse aggregates are composed of porphyritic fine-grained granite and fine to medium-grained granite. Fine aggregates are composed of porphyritic fine-grained granite and occasional fine to medium-grained granite. Sand is composed of granitic rock fragments, quartz and feldspar crystals. Some minor (<0.1„) cracks in the cement paste and ring cracks surrounding aggregate particles are possibly infilled with ettringite, some of them may also contain alkali-silica gel. A crack (1 mm) in the cement paste, connects with aggregate surfaces, is resin-infilled. Air voids are rare. Light grey cement paste when wet.

A4C 180-240 mm (vertical section)

Thin Section - Coarse (10-20 mm) aggregates are composed of porphyritic fine-grained granite (some weakly recrystallized). Fine (5-8 mm) aggregates are composed of porphyritic fine-grained granite (weakly recrystallized) and fine to medium-grained granite. Sand is composed of granitic rock fragments, quartz and feldspar crystals. About 15% of the cement paste is carbonated near cracks and the top of the slide. The cement paste is well hydrated (W/C = 0.5). Many cracks in the cement paste and ring cracks surrounding aggregate particles are commonly infilled with ettringite. Some cracks in the cement paste connect with ring cracks surrounding aggregate particles. Some air voids are internally bordered, sometimes completely infilled, with ettringite. Layered alkali-silica gel is present in the rings cracks of some aggregate particles.

Polished Slab - Coarse aggregates are composed of porphyritic fine-grained granite and occasional fine to medium-grained granite. Fine aggregates are rare and are composed of granitic rock fragments. Sand is composed of granitic rock fragments, quartz and feldspar crystals. Many minor (<0.1 mm) cracks in the cement paste (some connect with aggregate surfaces) are possibly infilled with ettringite and also may contain alkali-silica gel. Some ring cracks surrounding aggregate particles are internally bordered with possible ettringite. Air void is rare. Light grey cement paste when wet.

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APPENDIX 2

PRELIMINARY DISTRESS MEASUREMENTS
OF THE SEAWALL BLOCKS

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1. INTRODUCTION

Detailed *in situ* measurements of the exposed upper portions of the distressed seawall blocks at Tsang Tsui Ash Lagoon (Figure 1, Plate 1) were carried out in order to investigate the style of deformation and degree of volumetric expansion. The initial part of the survey involved calibration measurement of various dimensions of the undeformed seawall blocks, including leveling, alignment and inclination. This was followed by detailed measurements of similar aspects in the distressed seawall blocks. As these surveys are limited to the upper portions of the seawall blocks, it is recognized that they provide only a qualitative assessment of the deformation behaviour.

2. METHODOLOGY

2.1 Calibration Survey

Except for WW3, the monitored seawall blocks showing distress were originally cast *in situ* adjacent to two seawall blocks containing at least 25% PFA in the mix design (Table 1). For WW3, only one of the adjacent seawall blocks contained 25% PFA, while the other contained 0% PFA. The seawall blocks containing PFA showed no obvious signs of deterioration and it was assumed, therefore, that these blocks had sustained minimal distress since casting.

As no accurate as-built records of the dimensions of the seawall blocks were available, a calibration survey of the seawall blocks containing 25% PFA was carried out in order to measure any deviation from the original design dimensions provided by the consultants (Figures 2 & 3). The length (x-dimension) and width (y-dimension) of thirteen seawall blocks containing PFA (hereafter referred to as control blocks) were surveyed in detail. A total of six readings, comprising three readings in the x-direction and three readings in the y-direction, were taken for each control block, and the average and standard deviation for length and width calculated. The results for the control blocks (Table 2) show that the lengths vary from 2.422 to 2.515 m with an average of 2.488 m and standard deviation of 0.022 m, whereas the widths vary from 1.619 to 1.656 m with an average of 1.638 m and standard deviation of 0.011 m. The average length and width of the thirteen seawall blocks containing PFA are within less than 1% error of the original design width (1.65 m) and length (2.5 m). Therefore, these values, have been used as a basis for evaluating the relative distortion (x- and y-directions) in the distressed seawall blocks. Although not measured, the control block z-direction value (Figure 2 & 3) used in preliminary volumetric expansion calculations is taken from the design value (0.8 m).

In addition to measuring the x- and y-directions dimensions, it was necessary to measure other aspects of the control blocks against which motion and distortion in the distressed blocks could be evaluated. These aspects were: levelling, alignment and inclination. As the precise levelling, alignment and inclination of the distressed seawall blocks at the time of casting is likely to have varied slightly depending on location along the seawall, the average of leveling, alignment and inclination measurements in control blocks either side of each of the distressed seawall blocks was taken as the best point of reference. In the case of WW3 where only one of the adjacent blocks contained 0% PFA, the next adjacent seawall block was used. To ensure compatibility with the overall data set, the same calibration methodology was applied to the monitored control block (WW28). All except two of these measured blocks lay adjacent to distressed seawall blocks (Table 1).

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During the course of the calibration survey, it was discovered that the dimensions of two of the monitored seawall blocks (WW34 and WW35) were slightly shorter in the x-direction compared with the other seawall blocks (Table 2). Therefore, estimates of the relative motion and distortion of these blocks compared with the control blocks and other distressed blocks required special consideration. A discussion on these considerations and other potential sources of error in the measurements is given below.

2.2 Deformation Survey

The deformation survey on the seven monitored seawall blocks was carried out between February and March 2006 by the Survey Division of CEDD at the same time as the calibration survey (see Section 2.1). As with the calibration survey, the deformation survey comprised measurement of four aspects:- (i) general dimensions (Table 3); (ii) leveling (Table 4); (iii) alignment (Table 5) and (iv) inclination (Table 6).

(i) In the dimension measurement, the lengths (x-direction) and widths (y-direction) of the seawall blocks were measured by using a steel measuring tape. A total of six readings, comprising three readings in the x-direction and three readings in the y-direction, were taken at each block, and the average value was calculated. The method of dimension measurement is shown in Figure 4 and Plate 2.

(ii) Levelling was carried out by using a digital level with Invar staff with the aim of measuring the change in the top level of the distressed seawall blocks with reference to the adjacent control blocks. Four monitoring stations were installed on the top surface of each distressed and control block. The locations of the stations are shown in Figure 5. Plate 3 shows the location of the monitoring stations on each seawall block and Plate 4 shows a close-up view of the monitoring station.

(iii) The alignment measurement aimed to determine the seaward and landward expansions of the distressed seawall blocks. As shown in Figure 6, an arbitrary reference line was set out. The seaward expansion was obtained by comparing A6 and A10 with A7, A8 and A9. Similarly, the landward expansion was obtained by comparing A1 and A5 with A2, A3 and A4.

(iv) The inclination measurement aimed to determine the change in verticality of the landward face over depth. Measurement was carried out by placing a steel tape at a distance from the top of the block, and using plumb-line at the edge of the tape (Plate 5). The offset distances W1 to W4 were then measured to find the angular deviation at 200 mm, 400 mm and 600 mm from the top face of the

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block. Figure 7 shows the schematic representation of the measurement.

3. RESULTS

Measurements in the *x*-direction (Table 3) reveal that there is less than 0.03% difference between the measured and design values among the monitored seawall blocks. By contrast, five of the seawall blocks containing 0%PFA expanded in the y-direction, whereas WW34 and the control block (WW28) contracted (Table 3).

With respect to leveling measurements (Table 4), vertical expansion is recorded by all monitoring blocks when compared with the adjacent control blocks. The magnitude of expansion ranges from 6 mm to 25 mm. The descending order of expansion of the blocks is: WW3, WW35, WW9B, WW5, WW9A, WW34 and WW28.

The alignment measurements (Table 5) show that three blocks expanded in the landward direction whereas four blocks show contraction, compared with the adjacent control blocks. The descending order of expansion in the landward direction is WW9A, WW3 and WW9B, with the amount of expansion ranging from 2 mm to 3 mm. All seven blocks experienced expansion in the seaward direction. The descending order of expansion is WW35, WW34, WW9A, WW5, WW9B, WW28 and WW3. The amount of expansion ranges from 4 mm to 40 mm (equivalent to a 0.24% to 2.81% change) and with an average expansion of 15 mm.

Four seawall blocks experienced a bulging effect (Table 6). In descending order of bulging, these are WW34, WW3, WW5 & WW35. The average bulging angles ranged from 0.14 to 0.4 degrees, which are considered insignificant. The other distressed blocks (WW9B, WW9A) did not experience a bulging effect.

After measuring the upper dimensions of each distressed block and the adjacent control blocks, provisional volumetric changes were calculated (Table 7). The original length adopted was the average length measured for the seven monitoring blocks whereas the original width and depth were based on the design dimensions provided by the consultants (Figures 2 & 3).

Combining all the results, preliminary estimates of the volumetric expansions of all the seven blocks range from 0.20% to 3.94%. The descending order of expansion is WW3, WW35, WW9B, WW5, WW9A, WW34 & WW28.

4. CONCLUSIONS

The following preliminary conclusions can be made with respect to the deformation survey of the distressed seawall blocks at Tsang Tsui Ash Lagoons:

(a) Volumetric expansion is recorded by all of the monitored seawall blocks. The greatest expansion (3.94%) is shown by WW3 and the least expansion (0.20%) by the WW28.

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(b) The seawall blocks containing OPC (without PFA) generally show the greatest expansion. Seawall blocks containing SRC (without PFA) are the next least expansive, followed by the control sample containing OPC with PFA which shows the least expansion.

(c) All of the distressed seawall blocks show preferred expansion in the seaward direction.

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Table 1 - General Arrangement of Seawall Blocks at Tsang Tsui Ash Lagoons

Block →					5					10
1-10	SM	SM	5	SM	6	SM	SM	9B	SM	SM
11-20	SM	SM	3	7	SM	4	SM	2	SM	1
21-30	SM	SM	SM	SM	SM	SM	SM	SM	SM	SM
31-40	SM	SM	SM	SM	SM	SM	SM	SM	SM	SM
41-50	SM	SM	SM	SM	SM	SM	SM	SM	SM	SM
51-60	SM	SM	SM	SM	SM	SM	SM	SM	SM	SM
61-70	SM	SM	SM	SM	SM	SM	SM	SM	SM	SM
71-80	SM	SM	SM	SM	SM	SM	SM	SM	SM	SM
81-90	SM	SM	SM	SM	SM	SM	SM	SM	SM	SM
91-100	SM	SM	SM	SM	SM	SM	SM	SM	SM	SM
101-110	SM	SM	SM	SM	SM	SM	SM	SM	SM	SM
111-120	SM	SM	SM	SM	SM	SM	SM	SM	SM	SM
121-130	SM	SM	SM	SM	SM	SM	SM	SM	SM	SM
131-140	SM	SM	SM	SM	10	SM	SM	SM	12	SM
141-150	SM	SM	SM	9A	SM	11	SM	SM	SM	SM
151-160	SM	SM	SM	SM	SM	SM	SM	SM	SM	SM
161-170	SM	SM	SM	SM	SM	17	25	SM	27	SM
171-180	30	SM	SM	SM	28	SM	SM	SM	SM	SM
181-190	34	22	35	23	36	24	SM	SM	SM	SM
191-200	SM	SM	SM	SM	SM	SM	SM	SM	SM	SM
200-207	SM	SM	SM	SM	SM	SM	SM			

Control Block
SM = Standard Mix*

Monitored Block

*Standard Mix designed as a Grade 30 concrete made from 75% OPC and 25% PFA using 20 mm and 10 mm, aggregate and fine crushed granite rock supplied by Lamma Rock Products Ltd.

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Table 2 - Average Length and Width of Control Blocks

Control Blocks	Average Length (m)	Average Width (m)
L.H.S. of WW5	2.486	1.648
R.H.S. of WW5	2.471	1.650
L.H.S. of WW9B	2.501	1.640
R.H.S. of WW9B	2.499	1.656
L.H.S. of WW3	2.491	1.640
R.H.S. of WW7	2.422	1.650
L.H.S. of WW9A	2.487	1.623
R.H.S. of WW9A	2.515	1.619
L.H.S. of WW28	2.495	1.634
R.H.S. of WW28	2.491	1.636
L.H.S. of WW34	2.495	1.629
R.H.S. of WW34 (WW22)	2.492	1.631
R.H.S. of WW35 (WW23)	2.494	1.640
Average	2.488	1.638

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Table 3 - Dimension Measurements of Monitored and Control Blocks

	Control Block (L.H.S.)		Monitoring Block		Control Block (R.H.S.)		Increased Width of Monitoring Block Compared to Control Block	% Increase
	Average Length (m)	Average Width (m)	Average Length (m)	Average Width (m)	Average Length (m)	Average Width (m)		
WW 3	2.491	1.640	2.516	1.651	2.422	1.650	+0.013	0.79
WW 5	2.486	1.648	2.512	1.657	2.471	1.650	+0.019	1.16
WW 9A	2.487	1.623	2.502	1.647	2.515	1.619	+0.009	0.55
WW 9B	2.501	1.640	2.509	1.652	2.499	1.656	+0.014	0.85
WW 28	2.495	1.634	2.517	1.629	2.491	1.636	-0.009	-0.55
WW 34	2.495	1.629	2.300	1.634	2.492	1.631	-0.004	-0.24
WW 35	2.492	1.631	2.305	1.650	2.494	1.640	0.012	0.73

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Table 4 - Leveling Measurements of Monitored and Control Blocks

	Relative Level of Control Block (L.H.S)	Relative Level of Monitoring Block	Relative Level of Control Block (R.H.S)	Average Relative Level of Control Block (Avg)	Level Difference between Monitoring Block and Control Block (m)
WW 3	10.009	10.038	10.017	10.013	0.025
WW 5	9.996	10.011	10.000	9.998	0.013
WW 9A	10.081	10.095	10.090	10.086	0.010
WW 9B	9.992	10.018	10.013	10.002	0.015
WW 28	10.084	10.091	10.086	10.085	0.006
WW 34	10.090	10.104	10.101	10.095	0.008
WW 35	10.101	10.123	10.102	10.101	0.021
				Average:	0.014

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Table 5 - Alignment Measurements of Monitored and Control Blocks

Y-direction Expansion Towards Land Side

	X1 of Control Block (L.H.S.) (m)	Average of X2, X3 & X4 of Monitoring Block (m)	X5 of Control Block (R.H.S.) (m)	Average of X1 & X5 of Control Block (m)	Difference of Monitoring Block and Control Block (m)	% Change
WW 3	0.205	0.206	0.201	0.203	0.003	1.642
WW 5	0.212	0.210	0.213	0.213	-0.002	-1.020
WW 9A	0.188	0.196	0.198	0.193	0.003	1.727
WW 9B	0.202	0.206	0.205	0.204	0.002	1.229
WW 28	0.2	0.188	0.196	0.198	-0.010	-5.219
WW 34	0.193	0.180	0.205	0.199	-0.019	-9.548
WW 35	0.198	0.179	0.203	0.201	-0.022	-10.889

Y-direction Expansion Towards Sea Side

	X6 of Control Block (L.H.S.) (m)	Average of X7, X8 & X9 of Monitoring Block (m)	X10 of Control Block (R.H.S.) (m)	Average of X6 & X10 of Control Block (m)	Difference of Monitoring Block and Control Block (m)	% Change
WW 3	1.436	1.445	1.447	1.442	0.004	0.243
WW 5	1.435	1.447	1.432	1.434	0.014	0.942
WW 9A	1.44	1.450	1.429	1.435	0.016	1.104
WW 9B	1.438	1.446	1.44	1.439	0.007	0.486
WW 28	1.433	1.442	1.442	1.438	0.004	0.290
WW 34	1.434	1.454	1.428	1.431	0.023	1.607
WW 35	1.43	1.472	1.433	1.432	0.040	2.806
				Average:	0.015	1.068

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Table 6 - Inclination Measurements of Monitored and Control Blocks

	Average Inclination (Degrees)				
	Control Block (L.H.S)	Monitoring Block	Control Block (R.H.S)	Average of Control Block	Difference of Angle between Monitoring Block and Control Block
WW 3	0.525	0.780	0.286	0.406	0.374
WW 5	0.318	0.509	0.032	0.175	0.334
WW 9A	0.207	0.080	0.318	0.263	-0.183
WW 9B	0.000	-0.175	0.000	0.000	-0.175
WW 28	-0.398	-0.812	-0.653	-0.525	-0.286
WW 34	-1.209	-0.684	-0.955	-1.082	0.398
WW 35	0.000	0.000	-0.286	-0.143	0.143
				Average:	0.086

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Table 7 - Calculation of Volumetric Expansion of Monitored Blocks

	Length (m)	Assumed Original Width (m)	Final Measured Width (m)	Depth (m)	Measured Increase in Level (m)	Calculated Final Level (m)	Original Volume (m^3)	Volume after Expansion (m^3)	Increase in Volume (m^3)	% Increase in Volume
WW 3	2.488	1.638	1.651	0.8	0.025	0.825	3.260	3.389	0.129	3.94
WW 5	2.488	1.638	1.657	0.8	0.013	0.813	3.260	3.352	0.091	2.80
WW 9A	2.488	1.638	1.647	0.8	0.010	0.810	3.260	3.317	0.057	1.74
WW 9B	2.488	1.638	1.652	0.8	0.015	0.815	3.260	3.352	0.092	2.81
WW 28	2.488	1.638	1.629	0.8	0.006	0.806	3.260	3.267	0.006	0.20
WW 34	2.303	1.638	1.634	0.8	0.008	0.808	3.012	3.042	0.025	0.82
WW 35	2.303	1.638	1.650	0.8	0.021	0.821	3.012	3.121	0.104	3.44

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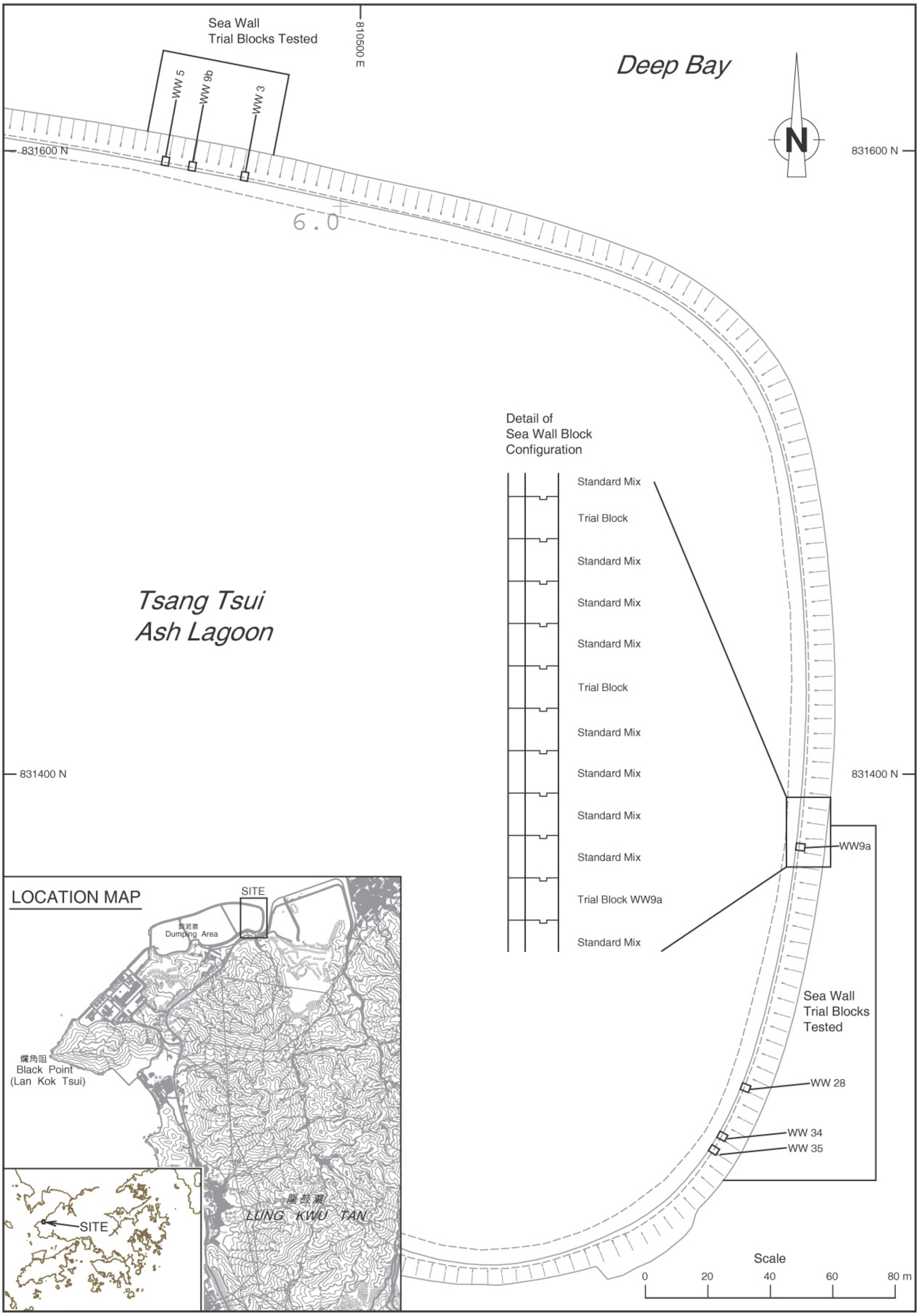

Figure 1 - General Location of Tsang Tsui Ash Lagoons and Layout of Seawall Blocks

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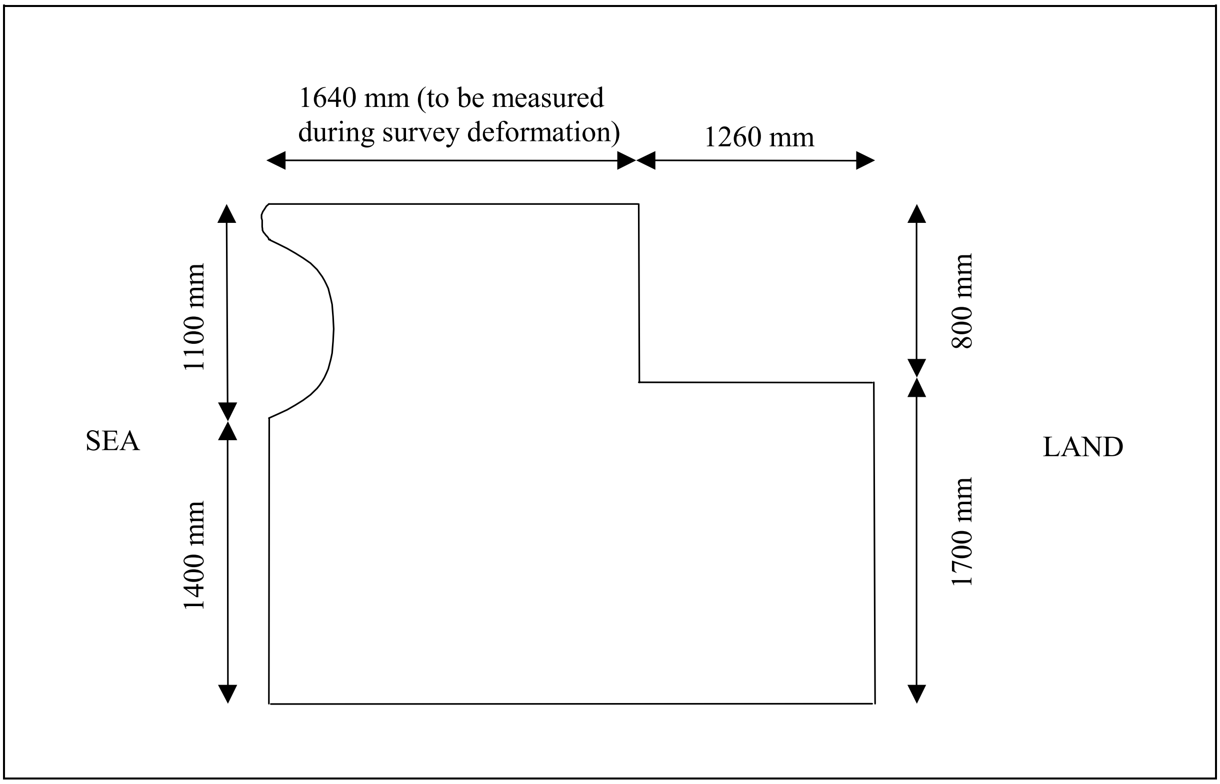

Figure 2 - Typical Section of a Seawall Block (provided by Consultants)

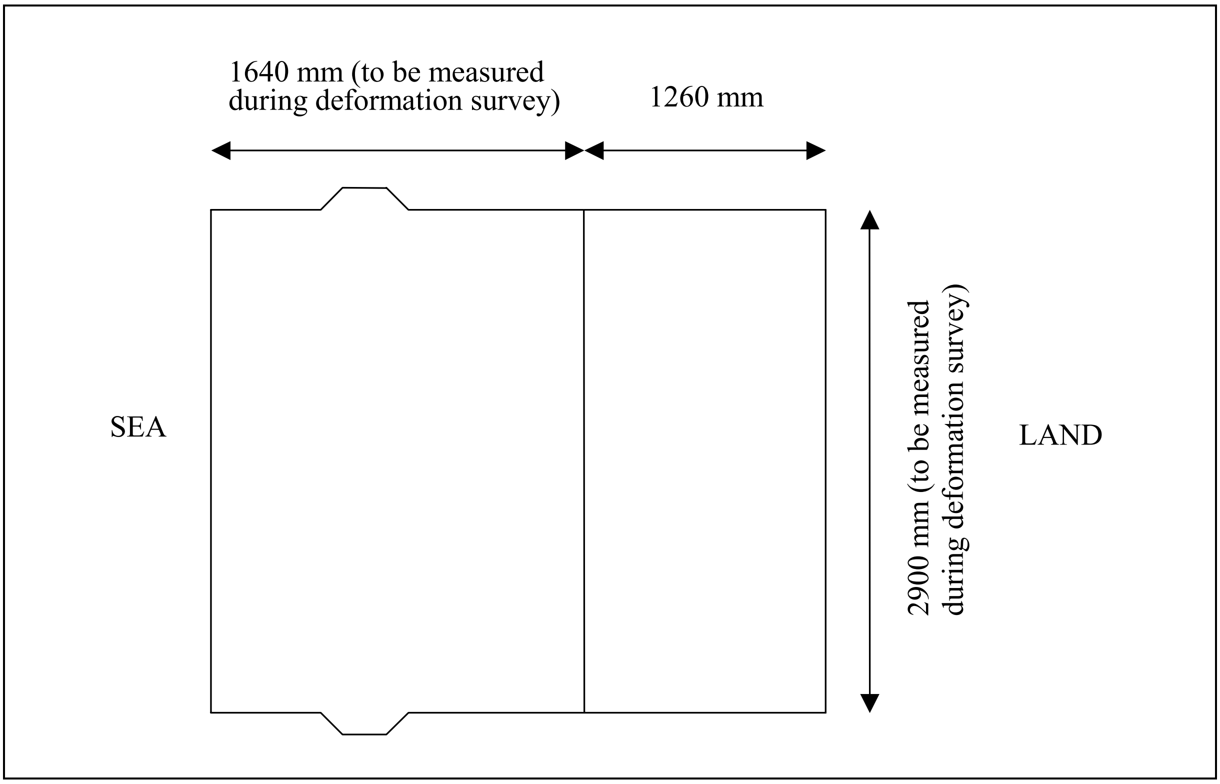

Figure 3 - Plan View of a Typical Seawall Block (provided by Consultants)

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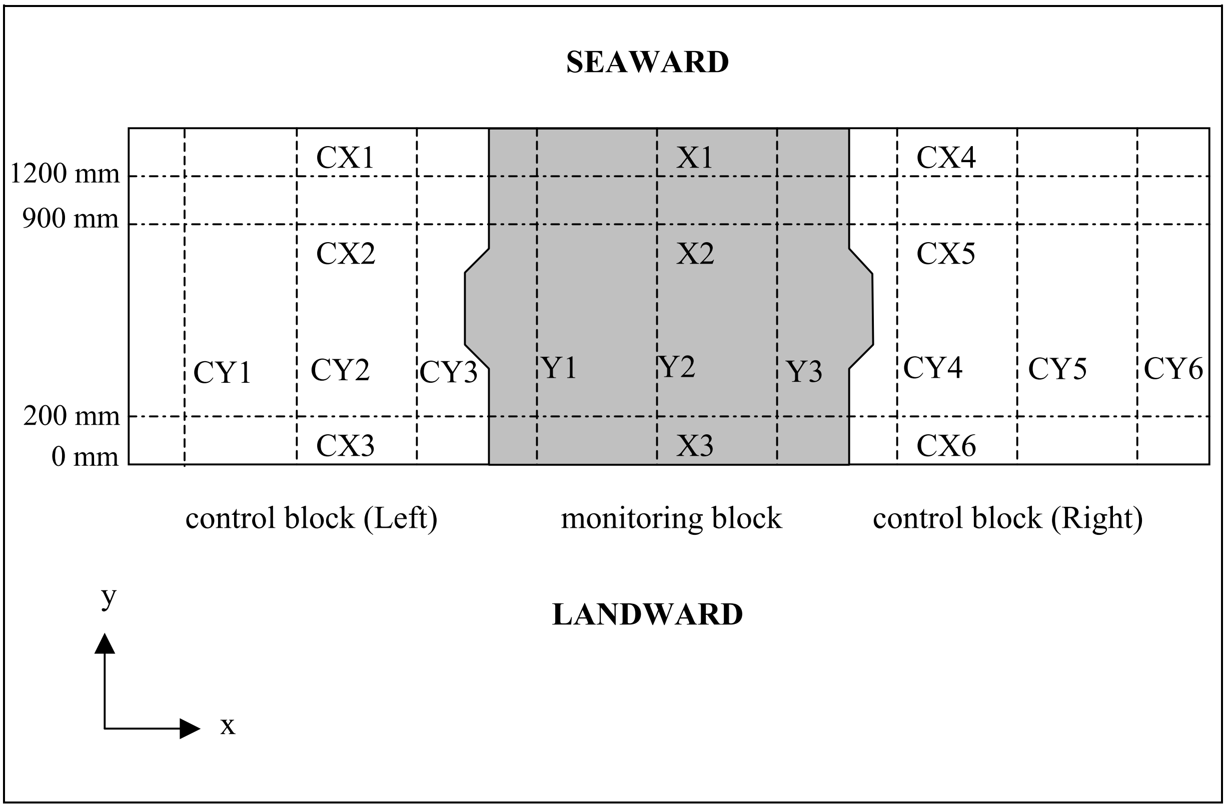

Figure 4 - Plan View of Seawall Blocks Illustrating Method of Dimension Measurement

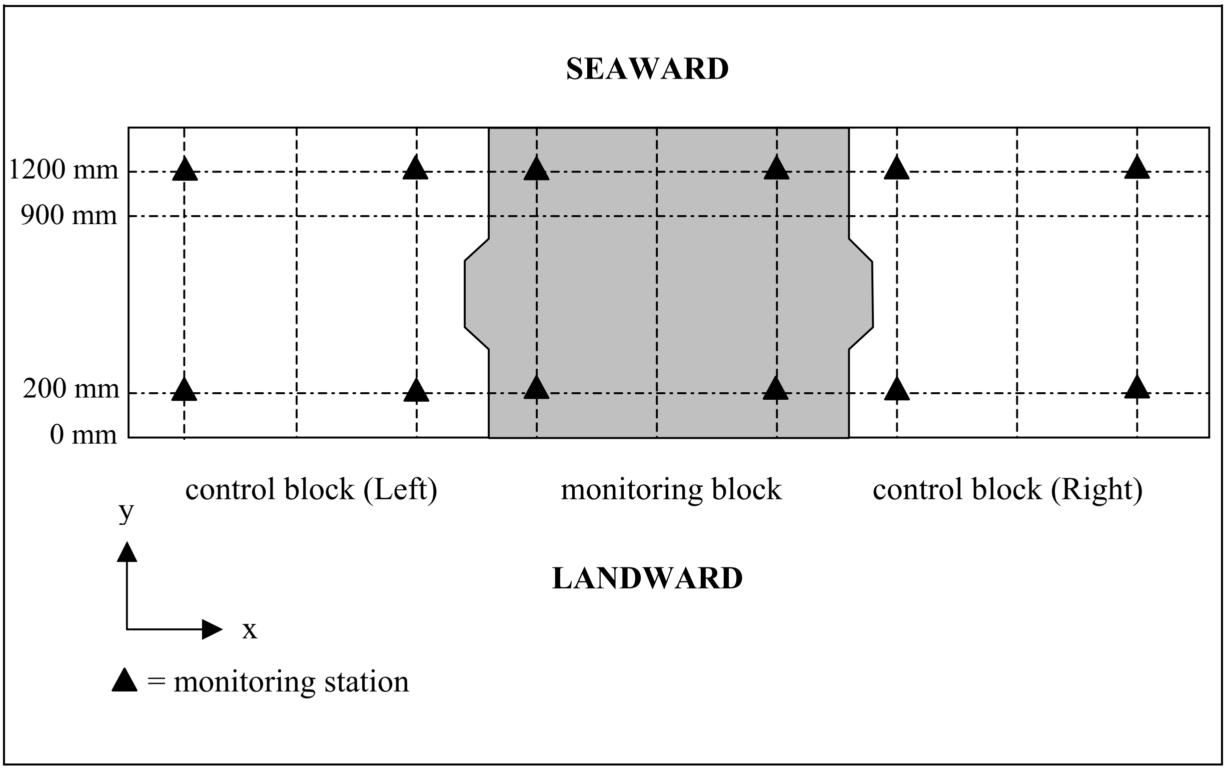

Figure 5 - Plan View of Seawall Blocks Showing Location of Monitoring Stations for Leveling

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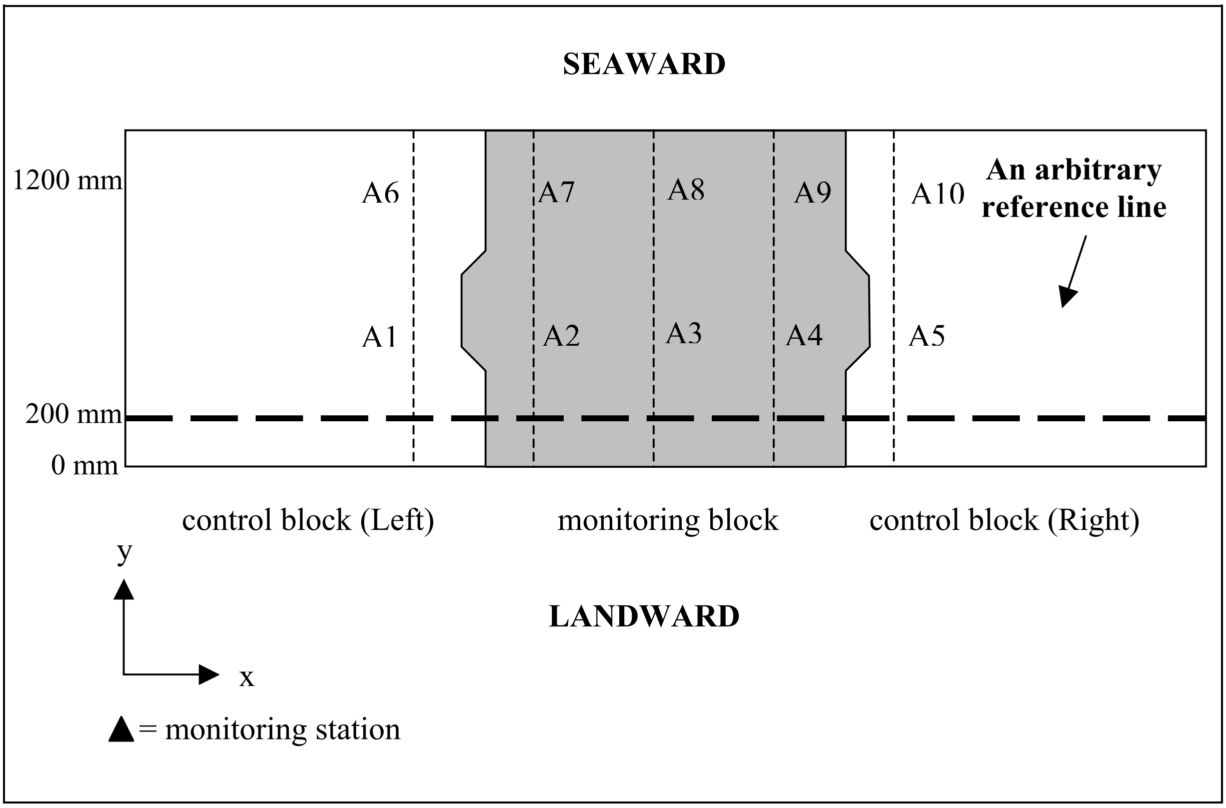

Figure 6 - Setting out of an Arbitrary Reference Line for Alignment Measurement

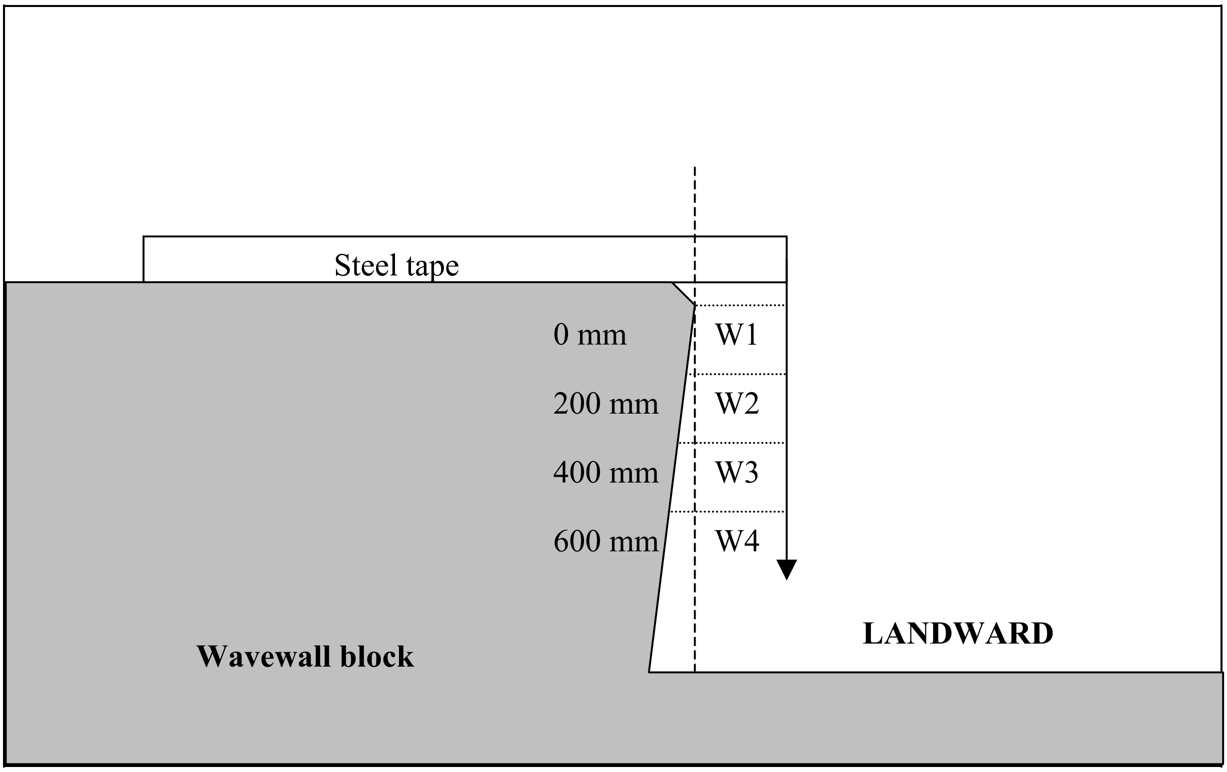

Figure 7 - Schematic Representation of Inclination Measurement

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Plate 1 - General View of the Seawall Blocks at Tsang Tsui Ash Lagoons Looking North

Plate 2 - Dimension Measurement Using a Steel Measuring Tape

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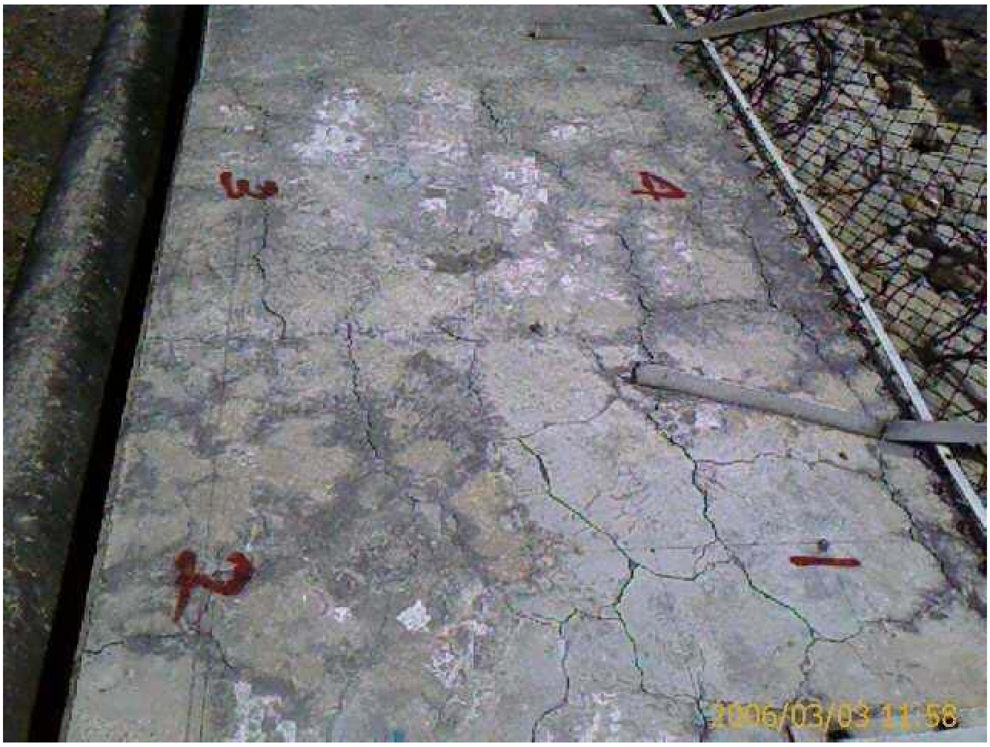

Plate 3 - Location of Monitoring Stations on a Typical Seawall Block

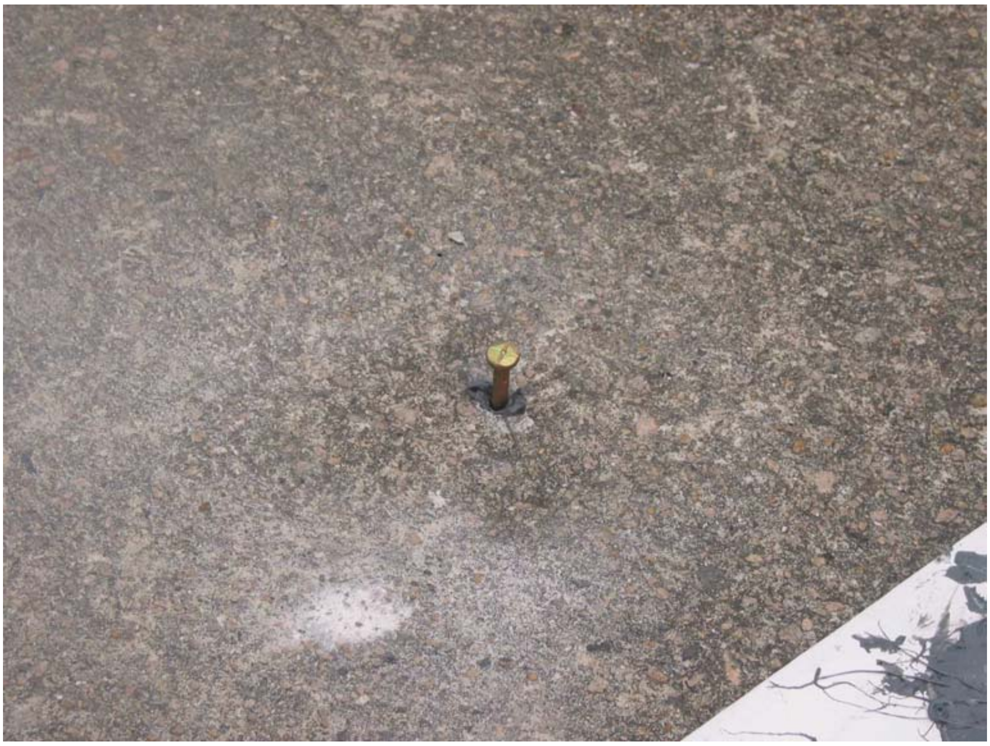

Plate 4 - Close-up of a Monitoring Station

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Plate 5 - Inclination Measurement Using a Steel Tape and a Plumb

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MAJOR GEOTECHNICAL ENGINEERING OFFICE PUBLICATIONS
土力工程處之主要刊物

GEOTECHNICAL MANUALS

Geotechnical Manual for Slopes, 2nd Edition (1984), 300 p. (English Version), (Reprinted, 2000).

斜坡岩土工程手冊(1998)，308頁(1984年英文版的中文譯本)。

Highway Slope Manual (2000), 114 p.

GEOGUIDES

Geoguide 1	Guide to Retaining Wall Design, 2nd Edition (1993), 258 p. (Reprinted, 2007).
Geoguide 2	Guide to Site Investigation (1987), 359 p. (Reprinted, 2000).
Geoguide 3	Guide to Rock and Soil Descriptions (1988), 186 p. (Reprinted, 2000).
Geoguide 4	Guide to Cavern Engineering (1992), 148 p. (Reprinted, 1998).
Geoguide 5	Guide to Slope Maintenance, 3rd Edition (2003), 132 p. (English Version).
岩土指南第五冊	斜坡維修指南，第三版(2003)，120頁(中文版)。
Geoguide 6	Guide to Reinforced Fill Structure and Slope Design (2002), 236 p.

GEOSPECS

Geospec 1	Model Specification for Prestressed Ground Anchors, 2nd Edition (1989), 164 p. (Reprinted, 1997).
Geospec 3	Model Specification for Soil Testing (2001), 340 p.

GEO PUBLICATIONS

GCO Publication No. 1/90	Review of Design Methods for Excavations (1990), 187 p. (Reprinted, 2002).
GEO Publication No. 1/93	Review of Granular and Geotextile Filters (1993), 141 p.
GEO Publication No. 1/2000	Technical Guidelines on Landscape Treatment and Bio-engineering for Man-made Slopes and Retaining Walls (2000), 146 p.
GEO Publication No. 1/2006	Foundation Design and Construction (2006), 376 p.
GEO Publication No. 1/2007	Engineering Geological Practice in Hong Kong (2007), 278 p.

GEOLOGICAL PUBLICATIONS

The Quaternary Geology of Hong Kong, by J.A. Fyfe, R. Shaw, S.D.G. Campbell, K.W. Lai & P.A. Kirk (2000), 210 p. plus 6 maps.

The Pre-Quaternary Geology of Hong Kong, by R.J. Sewell, S.D.G. Campbell, C.J.N. Fletcher, K.W. Lai & P.A. Kirk (2000), 181 p. plus 4 maps.

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