# COLLABORATIVE RESEARCH ON TESTING OF ALKALI SILICA REACTIVITY INVESTIGATION INTO CURING FACILITIES FOR ACCELERATED CONCRETE PRISM TEST

**GEO REPORT No. 255**

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**GEOTECHNICAL ENGINEERING OFFICE**

**CIVIL ENGINEERING AND DEVELOPMENT DEPARTMENT**

**THE GOVERNMENT OF THE HONG KONG**

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# COLLABORATIVE RESEARCH ON TESTING OF ALKALI SILICA REACTIVITY INVESTIGATION INTO CURING FACILITIES FOR ACCELERATED CONCRETE PRISM TEST

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**W.S. Chiang**

**This report is largely based on GEO Special Project Report No. SPR 6/2008 produced in December 2008**

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# PREFACE

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R.K.S. Chan
Head, Geotechnical Engineering Office
September 2010

# FOREWORD

At the request of the Standing Committee on Concrete Technology, the Public Works Central Laboratory (PWCL) of the Standards and Testing Division coordinated a collaborative study on testing of alkali silica reactivity. The objective is to investigate into curing facilities for accelerated Concrete Prism Test and to determine dominating factors and identify any room for alternative design of curing storage.

The collaborative research was carried out jointly by Department of Building and Construction of City University of Hong Kong (CUHK), Department of Civil and Structural Engineering of The Hong Kong Polytechnic University (HKPU) and Department of Civil Engineering of Hong Kong University of Science & Technology (HKUST) and PWCL. The Concrete Unit of PWCL was responsible for the overall planning and coordination of the Study. All contributions are gratefully acknowledged.

This report was prepared by Mr. W.S. Chiang.

W.K. Pun
Chief Geotechnical Engineer/Standards and Testing

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# ABSTRACT

With reference to Clause 4.6 of RILEM TC - ARP/01/20 "Detection of Potential Alkali-Reactivity, Accelerated Method for Aggregate Combinations and Concrete Mix Designs Using Concrete Prisms" (AAR4), it specifies a detailed design of curing storage for the test. However, the proposed design is complicated and expensive. It may not be commercially viable for Hong Kong local situation. This study is to investigate any room for improvement and explore possible alternative equipment for curing storage.

The Study concluded that inside a container, as long as the temperature of the water can be maintained at 60 ± 2°C and is not less than the temperature of the air, the relative humidity inside the container will be very high and above 95%. It is not necessary to follow the design of reactor and container specified in AAR4 straightly.

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# CONTENTS

# 1. INTRODUCTION

1.1 The Standing Committee on Concrete Technology (SCCT) is formulating a framework to control expansion of concrete caused by alkali-silica reaction (ASR). In support, the Public Works Central Laboratory (PWCL) is developing test procedures to measure the ASR of concrete.

1.2 The RILEM has developed 3 laboratory tests for the measurement of ASR. They are Accelerated Mortar-Bar Expansion Test (designated as AAR2) (RILEM, 2000a), Concrete Prism Expansion Test (designated as AAR3) (RILEM, 2000b) and Accelerated (60°C) Concrete Prism Test (designated as AAR4) (RILEM, 2001). The main features of the tests are tabulated in Table 1.1.

1.3 As shown in the Table 1.1, AAR2 can provide test results in just over two weeks but the curing condition is highest (80ºC) and far from the realistic environment of normal structures. The curing condition of AAR3 is 38ºC and is comparatively closer to the realistic environment. However, it requires a long testing period of one year. AAR4 seems to be a compromised method at 60ºC and test period of 20 weeks. It was selected as the test method for this study.

1.4 Clause 4.6 of AAR4 specifies the detailed design of curing storage for the test. The design is complicated and expensive. It may not be commercially viable for Hong Kong situation. The purpose of this study is to investigate any room for improvement and explore possible alternative equipment for curing storage.

1.5 The test results are very sensitive to the skill and care of the operators. To develop the confidence in the tests, it is important that the test results conducted can be compared with other parties of the same quality and care under parallel test system. Therefore Department of Building and Construction of City University of Hong Kong (CUHK), Department of Civil and Structural Engineering of The Hong Kong Polytechnic University (HKPU) and Department of Civil Engineering of Hong Kong University of Science & Technology (HKUST) were invited to join with PWCL in this collaborative study.

1.6 Based on AAR4, RILEM TC191-ARP issued a report in April 2005 on suggested interpretation criteria (RILEM, 2005) to distinguish reactive and non-reactive aggregate. RILEM recommended that a maximum expansion criterion of 0.03% at 20 week to be set for non-reactive aggregates. It also found that none of the reactive combinations gave expansions below 0.05%. The criteria can be used as a comparison for this study.

# 2. OBJECTIVES OF THE STUDY

2.1 The objective of this study is to investigate dominating factors and identify any room for alternative design of curing storage such that a cost-effective design for specimen storage

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can be established.

## 3. DESCRIPTION OF THE STUDY

3.1 PWCL was responsible for the preparation of concrete prisms for the study. The dimension of each prism was 75 x 75 x 285 mm. For the curing of the prisms, each participant would develop a set of storage equipment based on the conditions specified in AAR4.

3.2 In accordance with AAR-4, the curing conditions shall be at a temperature of 60 ± 2°C and at 100% relative humidity.

3.3 After demoulding, the prism specimens were wrapped in weave cotton cloth and polythene and inserted in lay-flat tubing as suggested by PWCL in accordance with AAR4 Figure 3A. The specimens were then transferred to corresponding individual participant for their curing and measurement.

3.4 Before taking measurement, the specimens were cooled down in the containers as specified in AAR-4. The containers were placed in a room or cabinet at a temperature of 20 ± 2°C and relative humidity above 65% for 24 hours prior to taking measurements.

3.5 Measurements were taken in accordance with the schedule specified in RILEM AAR-4.

## 4. SETUP OF THE SPECIMEN STORAGE

### 4.1 Specimen Storage Requirements Given in AAR4

4.1.1 In accordance with AAR4, the storage was divided into two parts - reactor and sealed container. Reactor would provide an environment at temperature of 60 ± 2°C and a relative humidity as close as possible to 100 %. In order to achieve the requirement, the water level was maintained at 35 ± 5 mm in the bottom of the reactor. A reference for design of the reactor is shown in Figure 2 of AAR4 procedure.

4.1.2 A reference design of the container is also shown in Figure 1 of AAR4. It consisted of a sealable container stored in the reactor. The prisms would be placed at 15 mm above the water in the container. A baffle would be provided at the lid inside the container to avoid dripping condensation.

4.1.3 An alternative storage is shown in A4.6 of Annex A in AAR4. The storage included prism wrapping and stored in side containers in order to maintain a high relative humidity around the wrapped prisms during storage. A reference design of the alternative container is shown in Figure A-3 of AAR4.

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## 4.2 Pre-Study Investigation

4.2.1 In order to check the sensitivity of thermal expansion of a prism, the change in length of a prism with temperature was also investigated. Prisms were cured in temperatures of 18, 21, 24 and 27°C and 95% relative humidity for 24 ± 0.5 hours respectively. The expansion was measured and the results were shown in Figure 4.1. It showed that the temperature during measurement of the prism was important.

4.2.2 On the other hand, as stated in Section 4.1, the governing conditions for curing were the storage temperature and relative humility. It should be achieved by a heating system installed in the reactor. The pre-study investigation had also checked the temperature and relative humility inside the container under various reactors.

4.2.3 Three types of reactors were investigated. They were (1) Hot water curing tank, (2) Environmental Chamber, and (3) Oven. The temperature of the reactors was set to 60 ± 2°C. As shown in Figure 4.2.1, a sealable plastic container was placed in the reactor for about 24 hours. The temperatures and relative humidity were measured and listed in Table 4.2.1.

4.2.4 It can be concluded from the above results that the container must be sealed otherwise the relative humidity inside the container might not reach the required values.

4.2.5 The relative humidity of 100% specified in the reactor might not be meaningful. The investigation showed that as long as the heater was submersed in the water of the reactor, the relative humidity within the reactor would be very high. However it was not directly related to the relative humidity inside the container. Furthermore, relative humidity of 100% would be very difficult to measure. Steam would be easily condensed at the relative humidity probe and then the reading would be misleading and read 100%. Under this situation the probe would not work properly.

4.2.6 Indeed, by investigating the arrangement, the relative humidity inside the container was "passive". As shown in the reference design of the container given in AAR4, there was no measure to increase or reduce the relative humidity inside the container. In fact, as long as water was present inside the container, the container was sealed and temperature of the air would not be higher than that of water, the relative humidity inside the container would be very high and close to 100%.

4.2.7 In a water tank, although the temperature of water was set to be 60°C the air temperature above the water might be below this temperature. It might be due to lack of circulation of air inside the tank. If the tank size were large this effect would be obvious. This problem did not occur in oven and environmental chamber because there were fans maintaining circulation.

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4.3 Setup of Apparatus

4.3.1 Length Comparator and Invar Rod - Figure 4.3.1 shows the comparator used to accommodate the shape of the reference studs in the prism. A digital or dial gauge mounted rigidly in vertical orientation was incorporated to the comparator. The graduation of the gauge was not greater than 0.002 mm and the error throughout the range of traverse was monitored to not more than 0.005 mm. An invar rod with ends machined to the reference studs was used. Since the comparator of HKPU was not compatible with studs used in PWCL, tailor-made adopters were required as shown in Figure 4.3.1b.

4.3.2 Container - Sealable plastic container were used in this study. The water depth at the bottom of container was maintained at 35 ± 5 mm and prisms were placed above the water. Details of container are shown in Figure 4.3.2. Each container could hold a minimum of three prisms. A baffle was attached to the cover to avoid dripping condensation onto the prism.

4.3.3 Reactor - The containers containing prisms were stored in a reactor maintained at a raised temperature of 60 ± 2°C and at 100 % relative humidity. Different types of reactor were used as shown in Figure 4.3.3.

4.3.4 Conditioning of Measurement Environment - Before measurement, the containers were stored at an environment of 20 ± 2°C and at relative humidity not less than 65 ± 5% for 24 ± 2 hours. The cooling conditions of the participants were shown in Figures 4.3.4.

## 5. SPECIMEN PREPARATION

5.1 The specimens were prepared by PWCL. In order to avoid sample variation, 18 numbers of prisms were cast from the same batch of mix at the same time.

5.2 The concrete prisms were marked with the name of participant, aggregate type, specimen number and top of the stud. In order to maintain moisture during delivery to relevant participants, the prisms were wrapped with wet towel and stored in a plastic box.

5.3 Two types of aggregates were selected for the test, namely Type A and Type B. Type A was known as ASR non-reactive local aggregate and Type B was ASR reactive local aggregate.

## 6 STUDY RESULTS

6.1 The expansions of prisms were measured in accordance with the schedule specified in AAR4 and shown in Figures 6.1 and 6.2.

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6.2 Type A aggregate has been identified as non-reactive aggregate. Figure 6.1 showed that the results obtained from PWCL and CUHK were comparable and the differences were small. The extension measurements at the first 20 weeks were in a range from 0.042% - 0.058%. The finding was not consistent with the suggested expansion criterion given in RILEM/TC-ARP/0511 that suggested non-reactive aggregate should give expansion not exceeding 0.03%.

6.3 Negative values were obtained in the results of HKUST. It indicated that the shrinkage dominated. The negative expansions were associated with mass loss. It was due to the low moisture content identified by monitoring of relative humidity of air inside the container.

6.4 For the results obtained from HKPU, the values were varied. The pattern was consistent with that from measured mass loss. It might be due to low moisture content.

6.5 Type B aggregate had been identified as high reactive aggregate. Figure 6.2 showed that apart from the result from HKUST, all results were in a range from 0.118% to 0.201%. The finding was consistent with the suggested expansion criterion given in RILEM/TC-ARP/0511 that suggested none of reactive mix measured below 0.05%. However, the range was quite large. Obviously, the result of the specimen cured in environmental chamber at PWCL was comparatively high and on the other hand the result from HKPU was comparatively low. Excluding those data, the results were close and in a range of 0.157% to 0.173%. There was not enough information to identify the reason causing the large variation.

6.6 The container of HKUST was placed on the floor of the environmental room. Although the room temperature was maintained at 60°C, the floor was cooler. Hence the relative humidity was not high enough and shrinkage occurred. After 20 weeks, the container was moved to a higher level, then the relative humidity automatically increased and expansion rapidly increased. Within 100 days the expansion was about 0.1%.

6.7 As shown in the Figure 6.1 and Figure 6.2, the expansion was not mature in twenty weeks; therefore, in PWCL, the measurement period was extended to about 70 weeks. Nevertheless, the expansions still did not cease.

6.8 In respect to the climate in Hong Kong, the specified temperature of AAR4 might not be high enough to accelerate the reaction. An investigation was carried out at the roof of PWCL building to measure the temperature of concrete during sunny days. The collected data showed that the temperature was very high and over 50°C in September 2006. In fact, it was not the hottest month of the year. Therefore, the specified temperature of 60°C in AAR4 might not practically be “accelerated” condition for ASR in Hong Kong.

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## 7. CONCLUSION

7.1 The specified relative humidity of 100% in the reactor is not meaningful. Since the containers are airtight the humidity in reactor will not affect the relative humidity of the container containing the specimen. In an oven the relative humidity will be very low but as long as there is water inside the container, the water will vaporize and the relative humidity inside the container will be very high automatically.

7.2 Temperature can be controlled by environmental chamber, oven or water tank. However, it is necessary to verify that the temperature inside the container can be maintained at the required level. For example, the temperature of water and air inside a water tank may not be equal which may affect the temperature inside the container. If an environmental room is used, the container should be placed at a suitable location to ensure that the temperatures of water and air inside the container are both at 60 ± 2°C.

7.3 It can be concluded that as long as the temperature of the water inside the container can be maintained at 60 ± 2°C, the relative humidity inside the container will be very high and above 95%. It is not necessary to follow the design of reactor and container specified in AAR4 strictly.

7.4 In respect to suggested expansion criterion given in RILEM/TC-ARP/0511, the results of local known reactive aggregate complied with the criterion but non-reactive aggregate did not. The value suggested in “Accelerated (60°C) Concrete Prism Test Suggested Interpretation Criteria” (RILEM, 2005) to identify ASR aggregate may not be applicable to Hong Kong.

7.5 It shows that the temperature of 60 ± 2°C specified in AAR4 may not be suitable for tropical areas such as Hong Kong, where temperature and relative humidity are very high.

## 8. REFERENCES

RILEM (2000a). TC 106-2 - Detection of Potential Alkali-Reactivity of Aggregates - The Ultra-Accelerated Mortar-Bar Test, Materials and Structure, Vol. 33, June 2000, pp 283 - 293.

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RILEM (2001). AAR-4 - Detection of Potential Alkali-Reactivity, Accelerated Method for Aggregate Combinations and Concrete Mix Designs Using Concrete Prisms, RILEM TC - ARP/01/20.

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RILEM (2005). Accelerated (60°C) Concrete Prism Test Suggested Interpretation Criteria, RILEM TC191-ARP, RILEM/TC-ARP/05/11.

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| Test Designation | Specimen Dimension (in mm) | Curing Condition | Testing Period (note 2) |
|---|---|---|---|
| AAR2 | Length 285<br>Cross-section 25 x 25 | Immersed in 80 ± 2ºC<br>1M NaOH solution | 16 days |
| AAR3 | Length 250 ± 50<br>Cross-section<br>75 x 75 ± 5 | Stored in specially designed container and temperature of 38 ± 2ºC | 52 weeks |
| AAR4 | Length 250 ± 50<br>Cross-section<br>75 x 75 ± 5 | Stored in specially designed container, temperature 60 ± 2ºC and relative humidity close to 100% | 20 weeks |

Notes: (1) Detailed differences shall be referred to the corresponding procedures.
(2) As recommended by RILEM, if so desired, measurement may be continued beyond the suggested test period.

Table 4.2.1 - Temperature and Relative Humidity of Container in Different Reactors

| Description | Temp. of Reactor (°C) | Temp. of Water in Plastic Container (°C) | Temp. of Air in Plastic Container (°C) | R.H. of Air in Plastic Container (%) |
|---|---|---|---|---|
| Sealed plastic container partial immersed (about 40mm) in water in a covered hot water curing tank. | 58.3 | 57.3 | 55.5 | 100 |
| Sealed plastic container placed in 100mm above hot water level in a covered hot water curing tank. | 53.4 | 53.8 | 53.5 | 100 |
| Sealed plastic container placed in an environmental chamber | 61.6 | 58.8 | 60.0 | 100 |
| Sealed plastic container placed in an oven | 58.2 | 58.3 | 58.5 | 100 |
| Covered plastic container without sealing and placed in an oven | 59.6 | 50.2 | 56.1 | 45.7 |

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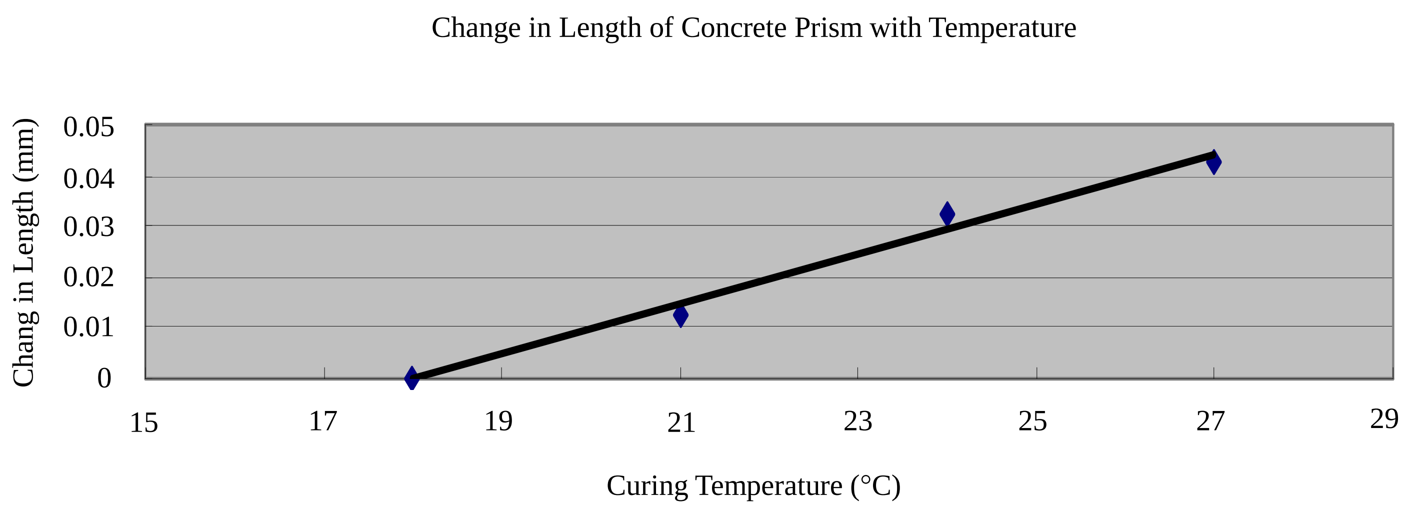


Figure 4.1 - Change in Length of Prism with Temperature



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Figure 4.2.2 - The Container Was Sealed and Conditioned in An Environmental Chamber.



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Figure 4.3.1d - Comparator with Digital Gauge and Invar Bar Used in PWCL

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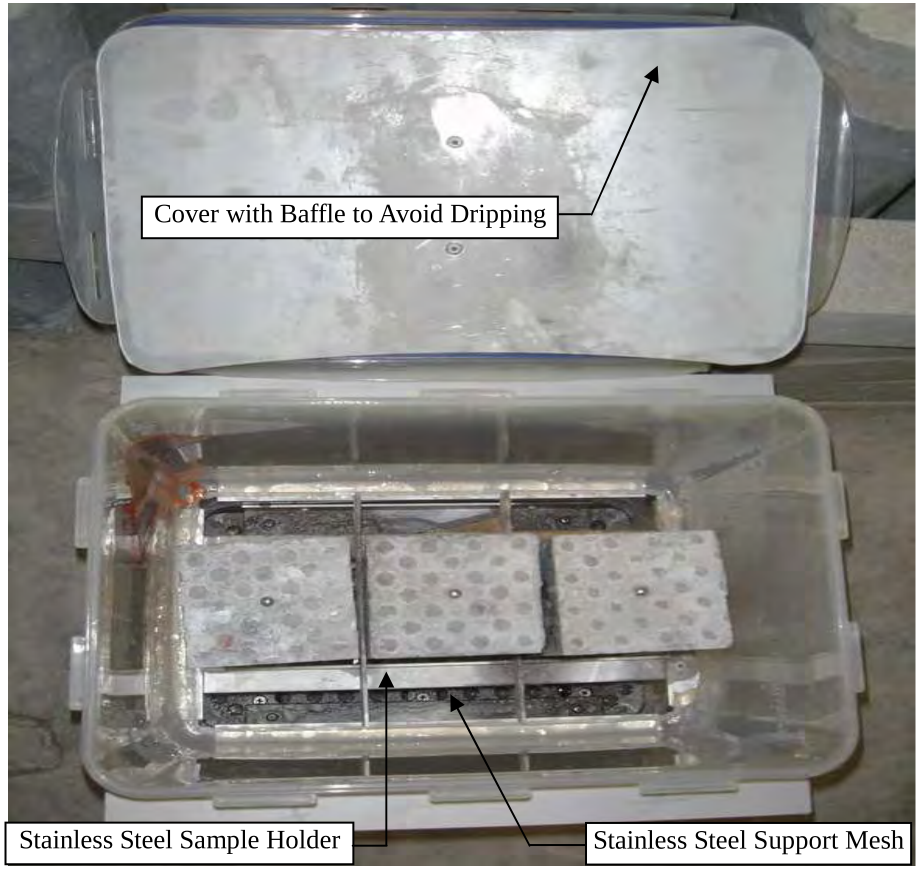


Figure 4.3.2a - Sealable Container with Prisms Used in CUHK

Figure 4.3.2b - Sealable Container with Prisms Used in HKPU

Figure 4.3.2c - Sealable Container with Prisms (Top) and Cover with Baffle (Lower) Used in HKUST

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Figure 4.3.2e - Type B Container - Conceptual Design Air Tight Container and Baffle



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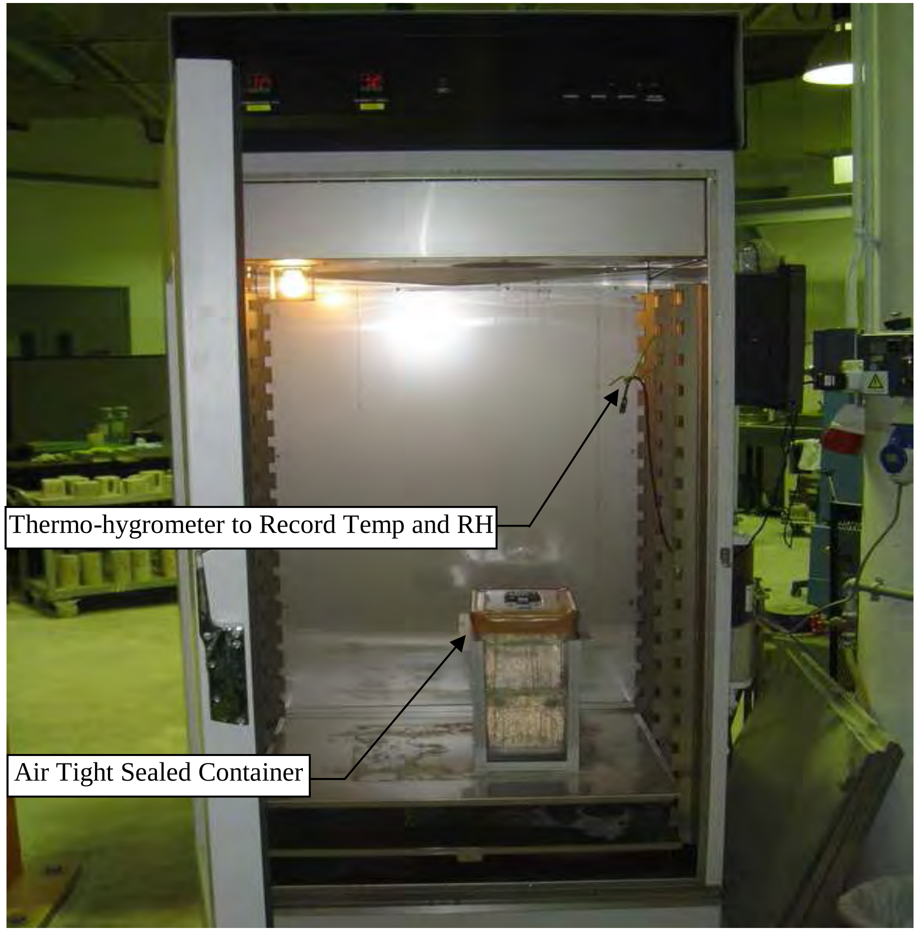


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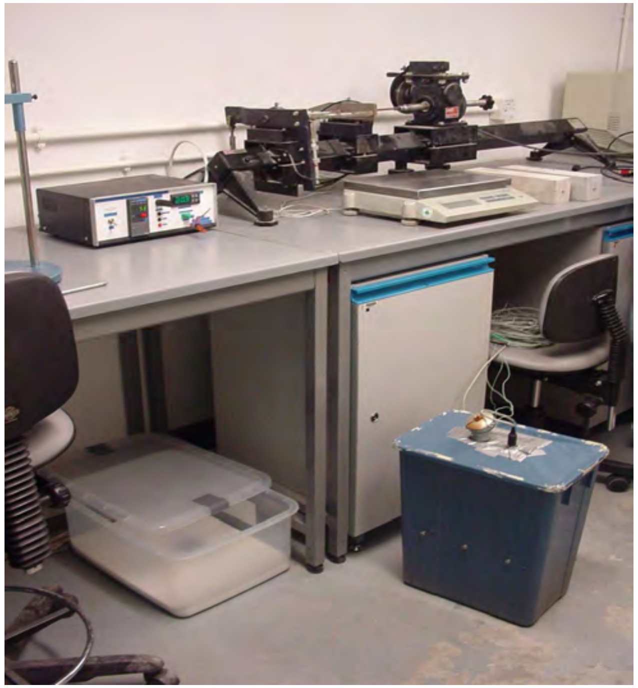


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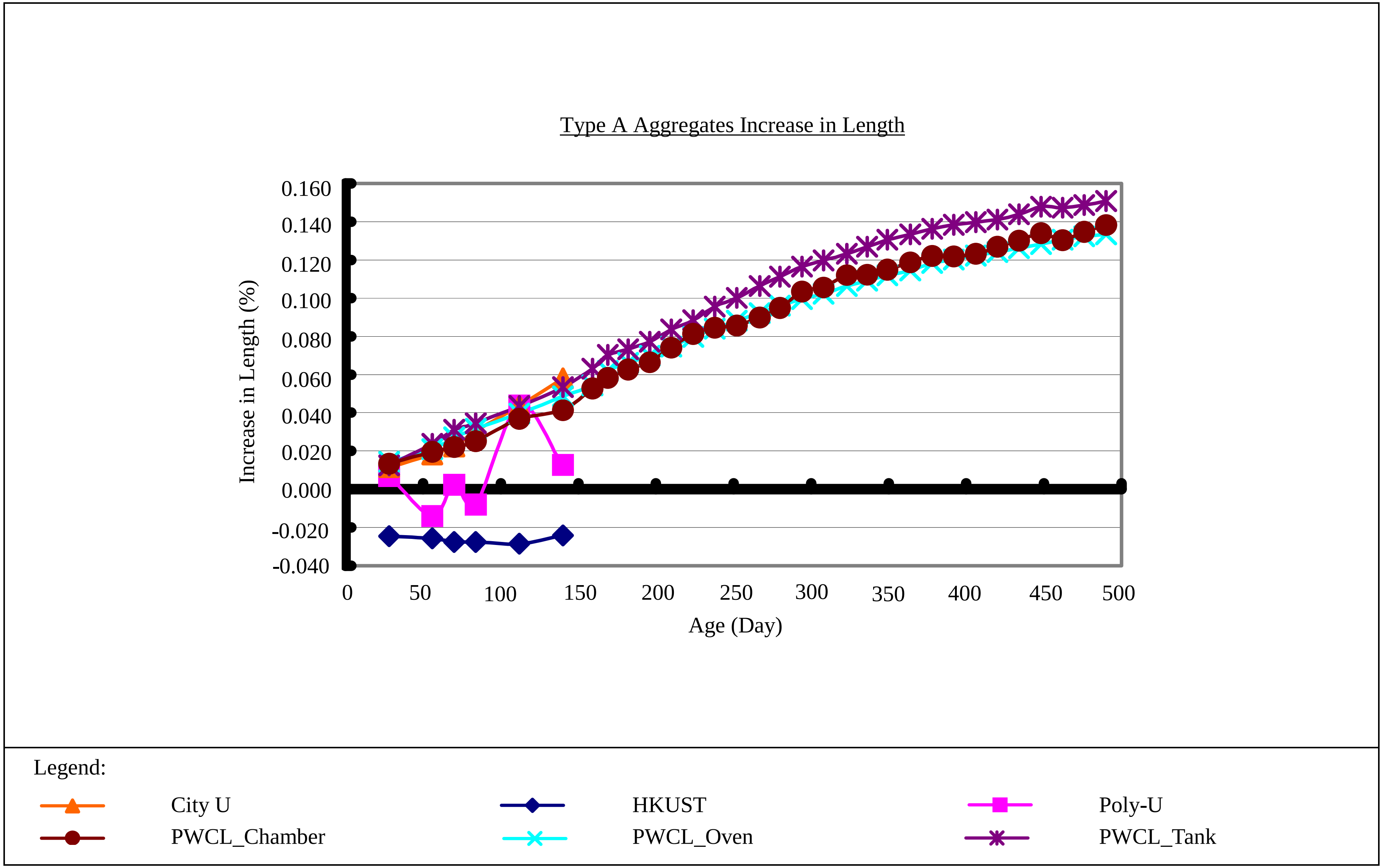


Figure 6.1 - Increase in Length of Type A Aggregate (Non-Active)



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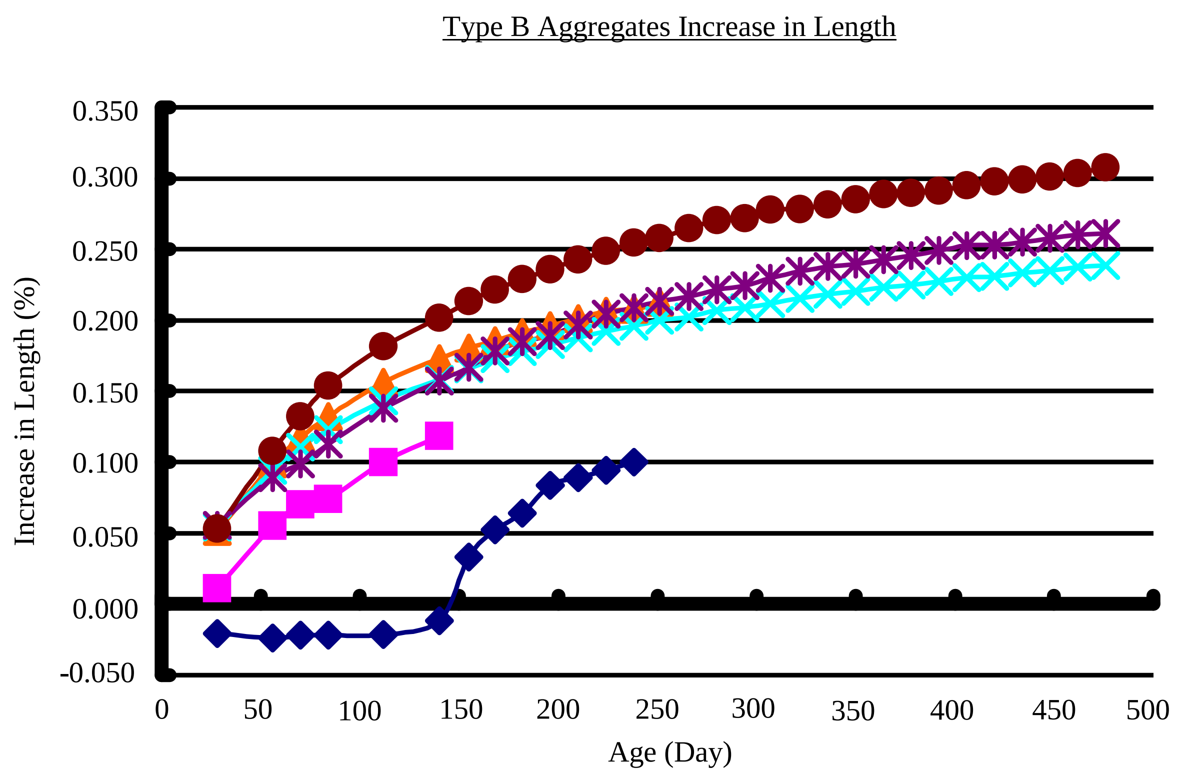


Legend:

| | | | | | |
|---|---|---|---|---|---|
| | City U | | HKUST | | Poly-U |
| | PWCL_Chamber | | PWCL_Oven | | PWCL_Tank |

Figure 6.2 - Increase in Length of Type B Aggregate (High Reactive)



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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

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| 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. |
| Geoguide 7 | Guide to Soil Nail Design and Construction (2008), 97 p. |

## GEOSPECS

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| 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

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| 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. |
| GEO Publication No. 1/2009 | Prescriptive Measures for Man-Made Slopes and Retaining Walls (2009), 76 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.

## TECHNICAL GUIDANCE NOTES

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