THE 2004 REVIEW ON PREVENTION OF ALKALI SILICA REACTION IN CONCRETE

GEO REPORT No. 167
(Second Edition)

Y.H. Chak & Y.C. Chan

GEOTECHNICAL ENGINEERING OFFICE

CIVIL ENGINEERING AND DEVELOPMENT DEPARTMENT

THE GOVERNMENT OF THE HONG KONG

SPECIAL ADMINISTRATIVE REGION

THE 2004 REVIEW ON PREVENTION OF ALKALI SILICA REACTION IN CONCRETE

GEO REPORT No. 167
(Second Edition)

Y.H. Chak & Y.C. Chan

This report was originally produced in June 2005
as GEO Special Project Report No. SPR 5/2005

First published, June 2005
Second Edition, January 2008

Prepared by:

Geotechnical Engineering Office,
Civil Engineering and Development Department,
Civil Engineering and Development Building,
101 Princess Margaret Road,
Homantin, Kowloon,
Hong Kong.

PREFACE

In keeping with our policy of releasing information which may be of general interest to the engineering 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.

The Geotechnical Engineering Office also produces documents specifically for publication. These include guidance documents and results of comprehensive reviews. These publications and the printed GEO Reports may be obtained from the Government's Information Services Department. Information on how to purchase these documents is given on the second last page of this report.

R.K.S. Chan
Head, Geotechnical Engineering Office
January 2008

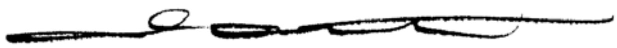
FOREWORD

Alkali-silica reaction (ASR) was first reported in Hong Kong in 1991. A control framework was introduced in 1994 based on the best practice then. The framework has worked well.

In the ten years since, there has been important advancement in the state of knowledge and practice of ASR control and use of alkali-reactive aggregates in concrete in the world. Experience and information on alkali reactivity of aggregates in Hong Kong have also built up. A review was therefore carried out in 2004 on the wealth of information, to examine the need for and the way of improving the existing ASR control framework. This report documents the review and proposes an expanded ASR control framework for use in Hong Kong.

The review was carried out by Mr CHAK Yu-hung, Steven under my supervision. Dr Diarmad Campbell assisted in the review of local practice. Drafts of the report and the proposed control framework were examined and discussed by members of the Standing Committee on Concrete Technology and the Consultative Committee on the Review of Concrete Related Standards. Other local practitioners knowledgeable about the subject have also given views. They include Dr Malcolm Anderson, Dr Fung Wing-kun, Mr Peter WC Leung, Mr Liu Kwong-kin, Kelvin, Mr Anthony Read, and Mr Wong Po-chi. Their contributions are gratefully acknowledged.

Finally, I wish to give my sincere thanks to Dr Sue Freitag, Dr Viggo Jensen, Dr Philip Nixon, Dr Hermann Sommer, and Professor Tang Ming-shu, renowned ASR experts of the world, for their comments. It is an unwarranted privilege for this report to benefit from their wealth of experience and international perspective.



Y C Chan
Deputy Head of the Geotechnical Engineering Office
(Planning and Standards)

ABSTRACT

Alkali-Silica Reaction (ASR) was first diagnosed on concrete structures in Hong Kong in 1991. Limitation of alkali content in concrete to 3kg/m^3 was introduced in 1994 to control ASR. The present review was carried out to see whether and how to update the control approach.

Current practice in the world is to accept the use in concrete of reactive aggregates to various degrees. The risk of ASR is controlled through the prescription of preventive measures taking into account the nature of structures, the service environment of the structure, and the reactivity of aggregates available. In this light, there is room for expanding the control framework in Hong Kong for informed use of reactive aggregates in concrete.

The nature of structures is classified according to the consequence of ASR. Service environment is described in terms of availability of moisture and alkali/chloride from outside the structure. Reactivity is classified by a range of tests including petrographic examination, accelerated mortar test and concrete prism test.

Common preventive measures are limiting alkali content of concrete, addition of supplementary cementitious materials such as pulverized fuel ash and ground granulated blast-furnace slag, and controlling the content of reactive silica in the aggregate assemblage of a concrete.

Knowledge and experience of ASR and its prevention in Hong Kong was reviewed for formulating the preventive measures for the expanded control framework. For the special case of reinforced concrete in marine environment, ingress of chloride ion presents a more immediate and demanding challenge than ASR to the durability of reinforced concrete in marine environment. This is provided for by an existing set of special specification.

The text of the report describes key elements of international practices and shows the rationale behind the proposed expanded ASR control framework for Hong Kong. Appendix H describes the expanded control framework. The other Appendices provide detailed information of local and international experience and practices. Of particular relevance to readers in Hong Kong are Appendix G and Appendix I that describe local experience and practice.

CONTENTS

1. BACKGROUND

Alkali silica reaction (ASR) was first observed in Hong Kong in 1991. Hobbs (1988) described mechanisms of ASR. A review of international practice led to the formulation of a framework for controlling the risk of ASR in Hong Kong. The framework, as described in WBTC 5/1994 (WB, 1994), requires limiting alkali content in concrete to 3.0 kg/m^3.

Hong Kong Quality Assurance Agency (HKQAA) operates a Quality Scheme for the Production and Supply of Concrete (QSPSC). All concrete supplied to public works projects has to be from QSPSC accredited producers (ETWB, 2002). One of the requirements of QSPSC is testing of alkali reactivity when an aggregate is first proposed for use (HKQAA, 2000). The presumption is that aggregates found to be reactive would not be accepted for use.

Limiting concrete alkali content to 3.0 kg/m^3 may be too conservative for non-reactive aggregates or structures of lesser importance. The alkali content limit should enable aggregates of some reactivity to be used satisfactorily but, under the present framework, once an aggregate is known to be reactive, they cannot be used.

For these and other reasons, the Public Works Central Laboratory (PWCL) commenced a review of international practice and local experience in 2003. Appendix A is a list of the documents reviewed. This report records findings of the review and proposes a new ASR control framework for use in Hong Kong.

2. EFFECT OF ASR

From the information available, no concrete structures had collapsed due to ASR damage. However, there were reports that some concrete structures were demolished because of ASR. For example, two prestressed bridges in Germany were demolished in the 1960s because of ASR (Hobbs, 1988).

L A Clark made a report ‘Critical review of the structural implications of the ASR in concrete’ in 1989 (West, 1996). Clark mentioned that ASR could reduce both the strength and the stiffness of concrete. He further noted that the possible severe ASR effect on isolated, unreinforced and unrestrained members may not be applicable to concrete in a structure where it is restrained by adjacent material. Tests on under-reinforced concrete beams and post-tensioned beams show no significant change in service load behaviour or reduction in strength as a result of severe ASR cracking. Moreover, loading tests on structures badly affected by ASR had not shown significant adverse effects on either strength or stiffness. The report concluded that in general ASR is unlikely to have a significant effect on ultimate strength. The effect would be on the durability and appearance of concrete structures; the life of concrete structures affected by ASR may be reduced and more frequent maintenance may be needed.

In Hong Kong, several concrete structures had been identified to suffer from ASR. At Fanling, water repellent protective coatings were applied on two footbridges to exclude the ingress of water. At Shek Wu Hui Treatment Plant, that part of ASR affected concrete at the inner faces of the aeration tanks had been blast-cleaned by sand and re-rendered with a mortar that contained a latex additive.

3. USE OF REACTIVE AGGREGATES

Nearly all the countries reviewed permit the use of reactive aggregates to some degree. ASR reaction is prevented by preventive measures including limiting the alkali content of concrete, addition of supplementary cementitious materials (SCM) such as pulverized fuel ash (PFA) and ground granulated blast-furnace slag (GGBS), or preclusion of reactive aggregates from particular uses. The mitigation requirements are usually organized into some form of frameworks.

4. CONCRETE MIX DESIGN FRAMEWORKS

Information on frameworks of concrete mix design to control ASR is summarized in Appendix B. There are three general forms of framework. In the first form, aggregates are classified as reactive or innocuous; preventive measures are prescribed for the use of reactive aggregates. In the second form, the reactivity of an aggregate is first classified; preventive measures are prescribed for use of the aggregate according to the nature of the structure and the environment it is in. In the third form, consideration starts with the nature of the structure to be constructed and the service environment; aggregate reactivity is considered for the choice of supply sources and the preventive measures needed to prevent ASR.

The first form of framework is simple but could be too conservative because the preventive measures would have to provide for the highest reactivity and worst service environment. The second form is useful for places where most aggregates are reactive so that the focus would be on how to make the best use of the aggregates. The third form is appropriate for places like Hong Kong where some aggregates are reactive and the framework aims at assisting the designer to decide whether and how to use reactive aggregates to suit the requirements of the project.

Common to the second and third forms of control framework are classifications of the structure to be constructed, service environment of the structures, and aggregate reactivity. Systems of classifying these attributes are discussed in the following Sections.

5. CLASSES OF STRUCTURE

Information on international practice for classifying structures for designing concrete against ASR is summarized in Appendix C. All adopt a three-tier system. The class descriptions can be generalized to that in Table 1.

6. SERVICE ENVIRONMENT

Information on ways of classifying service environment of structures or works is summarized in Appendix D. The general practice is to classify service environments to dry, moist, and moist aggressive. An example of the moist aggressive environment is high temperature when the concrete surface is wet.

In addition, Canada, New Zealand and RILEM include consideration of member size in the classification of service environment, for the reason that members over 0.5 m to 1.0 m at the thinnest are likely to remain wet internally irrespective of the ambient humidity. France and New Zealand do not distinguish between moist environment and moist aggressive environment when prescribing preventive measures against ASR.

Given the high humidity and the other considerations above, it is suggested that all concrete be designed for the moist aggressive environment in Hong Kong for ASR prevention. However, in the most unfavourable case of concrete in contact with seawater periodically, the need to control chloride ingress would impose addition requirements on concrete design. See SCCT (2000).

7. REACTIVITY TESTING AND CLASSIFICATION

International practice in testing and classifying alkali aggregate reactivity is summarized in Appendix E. Common tests are petrographic examination, accelerated mortar bar test (AMBT), and concrete prism test (CPT). CPT could be varied to test the effect of additives and variations in alkali content. The latter is the basis of the alkali threshold test proposed by RILEM (2005a).

Petrographic examination is commonly used to distinguish non-reactive rock from reactive rock. AMBT provides a quick test of reactivity in practice, as opposed to prediction based on petrography. Norway and RILEM also provide for grading alkali aggregate reactivity using AMBT results. CPT is generally accepted as the definitive test of reactivity and for classifying reactivity.

Most countries accept field performance to classify the reactivity of sources of aggregate.

A three-tier classification of reactivity is common. These include a non-reactive class and two classes of increasing certainty or degree of reactivity. Common class boundaries of AMBT and CPT results are shown in Table 2 together with those suggested for use in Hong Kong. For clarity, the three class names, when referred to in the rest of the report, would be capitalised as “Innocuous”, “Potentially Reactive”, and “Reactive”.

8. PREVENTIVE MEASURES

International practice of measures to reduce the likelihood of ASR of concrete is summarized in Appendices B and F. The common measures are limiting the alkali content of concrete, use of supplementary cementitious materials (SCM) such as PFA, modifying the gel chemistry, e.g. using lithium nitrate, and to change to a less reactive aggregate.

Experience with gel chemistry modification of concrete in Hong Kong is limited. The approach is not recommended for use in Hong Kong for the moment. Limits of alkali content or the percentage content of SCM to be used are summarized in Appendix F. The exact limits to be used should also tie in with local experience. This is the subject of the following Section.

9. LOCAL EXPERIENCE

Local experience on alkali reactivity of various sources of aggregate, field performance and effectiveness of preventive measures has been reviewed in Appendix G. The following picture emerges.

Granite is non-reactive but materials along shear zones and intrusions could be reactive. Unless quarried with suitable quality control, granite aggregate could be contaminated by the reactive materials; the resulting aggregate could be Potentially Reactive. Experience with concrete structures constructed since 1994 shows that controlling concrete alkali content to 3.0 kg/m^3 could likewise prevent ASR.

Local report of preventive measures for using reactive aggregates in concrete is very limited. Anderson and Read (2002) reported tests on the reactive aggregates from Anderson Road Quarry, which indicated that incorporating PFA in concrete could control ASR under some conditions.

Local experience of ASR in concrete in marine environment is absent. Effect of chloride ingress in concrete is a more immediate concern for reinforced concrete. SCCT (2000) prescribes measures to ensure durability of reinforced concrete in marine environment.

10. PROPOSED ASR CONTROL FRAMEWORK FOR HONG KONG

Based on the review in Sections 4 to 9, an ASR control framework has been proposed in Appendix H. The framework comprises two parts. The first is on concrete mix design. The second is on aggregate supply.

11. FURTHER WORK

RILEM is developing a control framework for international application (Nixon et al, 2004; RILEM, 2005a). The control framework proposed in this report aligns with the RILEM framework, except in respect of the method of classifying alkali silica reactivity of aggregates; the RILEM control framework uses alkali threshold to classify reactivity. Studies are needed to match local experience with ASR to this reactivity classification system.

The first component of these studies is the development of capability of concrete prism tests. PWCL has commenced work on this. The test capability will be used for benchmarking AMBT results against alkali thresholds defined by RILEM. It will also be used to conduct trials on the effectiveness of preventive measures proposed in the concrete mix design framework, especially those for reactive aggregates.

Work is in progress to examine quality assurance requirements for use with the proposed ASR control framework.

12. REFERENCES

Anderson, G.M. & Read, A.S. (2002). A Study on the Use of Volcanic Tuff Aggregate from Anderson Road Quarry in Concrete, Taywood Engineering Limited, 60 p.

Campbell, S.D.G. (2000). Petrographic Examination of Concrete Samples from Hill Road Flyover (H114) from Pok Fu Lam to Connaught Road West, GEO Informal Report IR 2/2000, 18 p.

Cement and Concrete Association of Australia (1996). Alkali Aggregate Reaction Guidelines on Minimising the Risk of Damage to Concrete Structures in Australia. Cement and Concrete Association C&CAA T47, Standards Australia SAA HB79, 31 p.

Cement and Concrete Association of New Zealand (2003). Alkali Silica Reaction - Minimising the Risk of Damage to Concrete Guidance Notes and Recommended Practice (Second Edition). Cement & Concrete Association of New Zealand, Technical Report No. 3, http://www.cca.org.nz/shop/downloads/TR03.pdf, 84 p.

CLP Power (2002). PFA Concrete Studies 1988-2000 Final Report. CD-Rom.

Concrete Society (1999). Alkali-silica Reaction: Minimising the Risk of Damage to Concrete - Guidance Notes and Model Clauses for Specifications. The Concrete Society, Technical Report 30, 3rd Edition, 72 p

CSA (2000). Concrete Materials and Methods of Concrete Construction/Methods of Test for Concrete. A23.1-00/A23.2-00, 9th edition, Toronto, 378 p

Environment Transport & Works Bureau (2002). Quality Assurance for Structural Concrete. ETWB TC(W) No 57/2002, 11 p.

Fournier, B., Bérubé, M.A. & Rogers, C.A. (2000). Canadian Standards Association (CSA) standard practice to evaluate potential alkali-reactivity of aggregates and to select preventive measures against alkali-aggregate reaction in new concrete structures. Proceedings of the 11th International Conference on Alkali-aggregate Reaction in Concrete, Quebec City, Centre de Recherche Interuniversitaire sur le Béton (CRIB) (Laval and Sherbrooke Universities) Département de génie civil, Université Laval, Quebec, pp 633-642

Geomaterials Research Services Ltd. (1993a). Report on the rocks and aggregate of Lamma Quarry by W.J. French. A report prepared for the Shui On Group.

Geomaterials Research Services Ltd. (1993b). Report on the examination of rock samples from Lamma Quarry by W.J. French. A report prepared for the Shui On Group.

Geomaterials Research Services Ltd. (1993c). 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.

Geomaterials Research Services Ltd. (1993d). Report on the petrography of samples of aggregate from Lamma Quarry by W.J. French. A report prepared for Taywood Engineering Limited.

Gibert, S.T. (1995). Petrographic Examination of Concrete Cores from Shek Wu Hui Treatment Plant, Geotechnical Engineering Office, Special Project Report SPR 4/95, 36 p.

Godart, B & Le Roux, A. (1992). The principles of AAR preventive measures adopted by the French Ministry of Equipment. Proceedings of the 9th International Conference on Alkali-aggregate Reaction in Concrete, London, The Concrete Society, pp 376-382

Guirguis, S. & Clarke, P. (2000). Alkali aggregate reactivity - towards standard test methods. Proceedings of the 11th International Conference on Alkali-aggregate Reaction in Concrete, Quebec City, Centre de Recherche Interuniversitaire sur le Béton (CRIB) (Laval and Sherbrooke Universities) Département de génie civil, Université Laval, Quebec, pp 653-662

HKQAA (2000). Quality Scheme for the Production and Supply of Concrete (QSPSC) Parts One & Two, Administrative Regulations & Technical Regulations, Issue 5, 38 p

Hobbs, D.W. (1988). Alkali-Silica Reaction in Concrete, Thomas Telford, Ltd, London, 183 p.

Hobbs, D.W. (2000). Alkali levels required to induce cracking due to ASR in UK concretes. Proceedings of the 11th International Conference on Alkali-aggregate Reaction in Concrete, Quebec City, Centre de Recherche Interuniversitaire sur le Béton (CRIB) (Laval and Sherbrooke Universities) Département de génie civil, Université Laval, Quebec, pp 189-198.

Jawed. I. (1992). Alkali-silica reactivity - a highway perspective. Proceedings of the 9th International Conference on Alkali-aggregate Reaction in Concrete, London, The Concrete Society, pp 471-476.

Liu, K.K. & Chan, C.Y. (2000). The Investigation of Cracking of the Concrete on Two Footbridges near Fanling KCR Station. Geotechnical Engineering Office, Special Project Report SPR 3/2000, 37 p.

Liu, K.K. & Tam, W.H. (2002). The Use of Accelerated Mortar Bar Test Methods for Assessment of Alkali-aggregate Reactivity of Aggregate in Hong Kong. Geotechnical Engineering Office, Technical Report TN 6/2002, 25 p.

Liu Y, Lee C F, Fu P X (2004) Alkali-silica reaction (ASR) characteristics of concrete made from granite aggregates, Proceedings of the 12th International Conference on Alkali Aggregate Reaction in Concrete, Beijing, pp369-376.

Malavar, L.J., Cline, G.D., Burke, D.F., Rollings, R., Sherman, T. & Greene, J. (2001). Alkali-silica Reaction Mitigation.: State-of-the-art. Naval Facilities Engineering Service Center, Report No. TR-2195-SHR, 40 p

Nixon, P. & Blackwell, B. (2000). New UK guidance and specifications to minimise risk of damage to concrete from ASR. Proceedings of the 11th International Conference on Alkali-aggregate Reaction in Concrete, Quebec City, Centre de Recherche Interuniversitaire sur le Béton (CRIB) (Laval and Sherbrooke Universities) Département de génie civil, Université Laval, Quebec, pp 723-732.

Nixon P., Hawthorn F. & Smith I (2004) Development of an international specification to combat AAR - proposals of RILEM TC 191-ARP. Proceedings of the 12th International Conference on Alkali Aggregate Reaction in Concrete, Beijing, pp 8-16.

Poole, A.B., Christopher, F.M. & Schrapel, K.N. (2000). Alkali-silica reaction in concrete related to alkali diffusion through the cement pore network. Proceedings of the 11th International Conference on Alkali-aggregate Reaction in Concrete, Quebec City, Centre de Recherche Interuniversitaire sur le Béton (CRIB) (Laval and Sherbrooke Universities) Département de génie civil, Université Laval, Quebec, pp 209-218.

Read, A.S. & Anderson, G.M. (2002). Volcanic Rock as Aggregate in Concrete Control of Alkali-silica Reaction (ASR) in Concrete in Hong Kong, KWP Quarry Co Ltd, 47 p.

RILEM (2005a). International Specification to Minimise Damage from Alkali Reactions in Concrete: Part 1 Alkali Silica Reaction, (Draft - March 2005) Internal Document No. RILEM/TC-ARP/05/08, 10 p.

RILEM (2005b). Accelerated (60°C) Concrete Prism Test - Suggested Interpretation Criteria. Internal Document RILEM/TC-ARP/05/11, 8p.

SCCT (2000). Recommended Specification for Reinforced Concrete in Marine Environment, Standing Committee on Concrete Technology, 4 p.

Sewell, R.J. (1999). Petrographic Examination of Concrete Cores from Fanling Footbridge, GEO Informal Report IR 1/99, 22 p.

Sewell, R.J. (2000). Petrographic Examination of Concrete Samples from Feature Nos. 11SE-A/C83 and C724 North Point Government School. Geotechnical Engineering Office, Geological Report GR 3/2000, 12 p.

Sewell, R.J. & Campbell, S.D.G. (2001). Petrographic Examination of Concrete Samples, GEO Report No. 119, 63 p.

Sewell, R.J., Ho, K.C., Leung, C.L. & Leung, K.Y. (2007). Causes and Mechanisms of Distress in Concrete Seawall Blocks at Tsang Tsui Ash Lagoons. Geotechnical Engineering Office, GEO Report No. 209, 116p.

Sims, I., Nixon, P.J. & Marion, A. (2004). International collaboration to control alkali-aggregate reaction: the successful progress of RILEM TFC 106 and TC191-ARP. Proceedings of the 12th International Conference on Alkal Aggregate Reaction in Concrete, Beijing, pp 41-50.

St John, D.A. (1992). Alkali-aggregate Investigation in New Zealand - Report on Work Carried Out Since 1989. Proceedings of the 9th International Conference on Alkali-aggregate Reaction in Concrete, London, The Concrete Society, pp 885-893

Swamy, R.N. (1992). The Alkali-silica reaction in concrete. Blackie and Son Ltd, Glasgow 336 p.

Taywood Maunsell Ltd. (1993). Independent geological assessment of Lamma Quarry as a source of concrete aggregate by W.J. French. A report prepared for the Kumagai-Maeda-Yokogawa-Hitachi JV by Taywood Maunsell Ltd.

Touma, W.E., Fowler, D.W. & Carrasquillo, R.L. (2001). Alkali-silica Reaction in Portland Cement Concrete: Testing Procedures and Mitigation Methods. International Centre for Aggregates Research, The University of Texas at Austin, Report No. ICAR 301-1F, 520 p.

West, G. (1996). Alkali-aggregate Reaction in Concrete Roads and Bridges. Thomas Telford Publications, London, 163 p.

Works Bureau (1994). Specification Clauses to Guard against the Occurrence of Alkali-aggregate Reaction in Concrete Structures. WBTC No 5/1994.

Wong, P.C. & Koirala, N.P. (1992). Interim Report - Investigation of Cracks at Shek Wu Hui Treatment Plant. Report prepared for the Standing Committee on Concrete Technology. Materials Division, Geotechnical Engineering Office, Hong Kong. 54 p.

LIST OF TABLES

Table 1 - Classification of Structures according to Potential Consequence of ASR

Class	Definition and Examples
1	Some deterioration from ASR is acceptable e.g., temporary or short service life structures, easily replaceable elements.
2	Minor ASR and resulting cosmetic cracking is acceptable e.g., most building and civil engineering structures, which design life is in the regime of tens to a hundred or so years.
3	No ASR damage is acceptable, even if only cosmetic - long service life or highly critical structures: e.g., nuclear installations, dams, tunnels, exceptionally important bridges or viaducts, structures retaining hazardous materials

Table 2 - Summary of Reactivity Classification Practice and the Proposed Scheme

Country	Acc. Mortar Bar*	Concrete Prism*	Petrography	Field Performance
HKMTRC	-----0.15----			
Read et al +	---0.1%---0.2%---			Yes
RILEM	---0.1%---0.2%---	---0.05%---0.10%---	Yes	Yes
Canada	-----0.15%-----	---0.04%---0.12%---	Yes	Yes
Denmark	Non-standard tests		Yes	
France	Non-standard tests		Yes	Yes
Japan	Non-standard tests			Yes
Netherlands	Non-standard tests		Yes	
Norway	---0.1%---0.25%---		Yes	
UK		---0.05%---0.1%-----	Yes	
USA	-----0.1%-----	-----0.04%-----	Yes	
Proposed #	---0.1%---0.2%---	---0.05%---0.10%---	Yes	Yes

Legend:

* ---0.1%---0.2%---: The first figure denotes the limit for the class of non-reactive rock; the second figure denotes that for the lower class of reactive rock

-----0.1%-----: The figure denotes the limit for the class of non-reactive rock

\+ Read & Anderson (2002): It proposed a five-tier classification for Hong Kong.

\# Proposed for use of the control framework described in Section 10.

APPENDIX A

BIBLIOGRAPHY OF DOCUMENTS REVIEWED

Overseas

Andrade, W. P. D. (2003). Aging and Rehabilitation of Concrete and Masonry Dams and Appurtenant Works. http://www.icold-cigh.org/Gr82.pdf, 93 p.

Barborak R, Folliand K J, Thomas M D A (2004) Using lithium compound to treat hardened concrete suffering from ASR: preliminary laboratory results, Proceedings of the 12th International Conference on Alkali Aggregate Reaction in Concrete, Beijing, pp 483-489.

Barisone, G. & Restivo, G. (1992). Alkali-silica reactivity of alluvial deposits evaluated using chemical and psammographic methods. Proceedings of the 9th International Conference on Alkali-aggregate Reaction in Concrete, London, pp 46-52.

Barisone, G. & Restivo, G. (2000). Alkali-silica reactivity of some italian opal and flints tested using a modified mortar bar test. Proceedings of the 11th International Conference on Alkali-aggregate Reaction in Concrete, Quebec City, Centre de Recherche Interuniversitaire sur le Béton (CRIB) (Laval and Sherbrooke Universities) Département de génie civil, Université Laval, Quebec, pp 239-245.

Barringer, W.L. (2000). Application of accelerated mortar bar tests to new Mexico aggregates. Proceedings of the 11th International Conference on Alkali-aggregate Reaction in Concrete, Quebec City, Centre de Recherche Interuniversitaire sur le Béton (CRIB) (Laval and Sherbrooke Universities) Département de génie civil, Université Laval, Quebec, pp 563-572.

Batic O R, Sota J D (2004) Identification of alkali-silica reactive granite aggregates, Proceedings of the 12th International Conference on Alkali Aggregate Reaction in Concrete, Beijing, pp 243-250.

Bektas F, Turanli L, Monteiro P J M (2004) A preliminary study of the efficiency of crushed brick blended cement in reducing ASR, Proceedings of the 12th International Conference on Alkali Aggregate Reaction in Concrete, Beijing, pp 479-482.

British Standards Institution (1985). Structural Use of Concrete. BS 8110: Parts 1 to 3:1985.

Carse, A. (2000). Testing of Australian concrete mixtures for alkali-silica reaction potential and calibration with field performance of structures. Proceedings of the 11th International Conference on Alkali-aggregate Reaction in Concrete, Quebec City, Centre de Recherche Interuniversitaire sur le Béton (CRIB) (Laval and Sherbrooke Universities) Département de génie civil, Université Laval, Quebec, pp 247-256.

Crosswell, S.F. (1992). Alkali-aggregate reaction in the western cape region of South Africa. Proceedings of the 9th International Conference on Alkali-aggregate Reaction in Concrete, London, The Concrete Society, pp 211-216.

Dahl, P.A. et al. (1992). Norwegian experience with different test methods for alkali aggregate reactivity. Proceeding of the 9th International Conference on AAR, London, pp 224-230.

Dahl, P.A. et al. (2004). Specifications and guidelines for production of AAR resistant concrete in Norway. Proceeding of the 12^{th} International Conference on AAR, Beijing, pp 499-504.

Fournier, B., Bérubé, M.A. & Frenette, J. (2000). Laboratory investigations for evaluating potential alkali-reactivity of aggregates and selecting preventive measures against alkali-aggregate reaction (AAR). Proceedings of the 11th International Conference on Alkali-aggregate Reaction in Concrete, Quebec City, Centre de Recherche Interuniversitaire sur le Béton (CRIB) (Laval and Sherbrooke Universities) Département de génie civil, Université Laval, Quebec, pp 287-296.

Fournier B, Nkinamubanzi P, Chevrier R (2004) Comparative field and laboratory investigations on the use of supplementary cementing materials to control alkali-silica reaction in concrete. Proceedings of the 12^{th} International Conference on Alkali Aggregate Reaction in Concrete, Beijing, pp 528-537.

Fournier et al (2004) The accelerated concrete prism test ($60^{O}C$): variability of the test method and proposed expansion limits. Proceedings of the 12^{th} International Conference on Alkali Aggregate Reaction in Concrete, Beijing, pp 314-323.

Franke, L., Eickermeier, K. & Bosold, D. (2000). Determination of the reactivity and the amorphous component for opalsandstones by the Rietveld method. Proceedings of the 11th International Conference on Alkali-aggregate Reaction in Concrete, Quebec City, Centre de Recherche Interuniversitaire sur le Béton (CRIB) (Laval and Sherbrooke Universities) Département de génie civil, Université Laval, Quebec, pp 297-304.

Freitag, S.A., St John, D.A. & Goguel, R. (2000) ASTM C1260 and the alkali reactivity of New Zealand greywackes. Proceedings of the 11th International Conference on Alkali-aggregate Reaction in Concrete, Quebec City, Centre de Recherche Interuniversitaire sur le Béton (CRIB) (Laval and Sherbrooke Universities) Département de génie civil, Université Laval, Quebec, pp 305-313.

French, W.J. & Howarth, R.J. (2000) The petrographic diagnosis of potneially deleterious aggregates. Proceedings of the 11th International Conference on Alkali-aggregate Reaction in Concrete, Quebec City, Centre de Recherche Interuniversitaire sur le Béton (CRIB) (Laval and Sherbrooke Universities) Département de génie civil, Université Laval, Quebec, pp 315-324.

Glauz, D. & Jain, V. (2000). California’s experience with reactive aggregates. Proceedings of the 11th International Conference on Alkali-aggregate Reaction in Concrete, Quebec City, Centre de Recherche Interuniversitaire sur le Béton (CRIB) (Laval and Sherbrooke Universities) Département de génie civil, Université Laval, Quebec, pp 325-334.

Grattan-Bellew, P.E. (1986). Concrete Alkali-aggregate Reactions. Noyes Publications, New Jersey, USA, 509 p.

Grosbois, M. & Fontaine, E. (2000). Evaluation of the potential alkali-reactivity of concrete aggregates: Performance of testing methods and a producer's point of view. Proceedings of the 11th International Conference on Alkali-aggregate Reaction in Concrete, Quebec City, Centre de Recherche Interuniversitaire sur le Béton (CRIB) (Laval and Sherbrooke Universities) Département de génie civil, Université Laval, Quebec, pp 267-276.

Grosbois, M. & Fontaine, E. (2000b). Performance of the 60°C - accelerated concrete prism test for the evaluation of potential alkali-reactivity of concrete. Proceedings of the 11th International Conference on Alkali-aggregate Reaction in Concrete, Quebec City, Centre de Recherche Interuniversitaire sur le Béton (CRIB) (Laval and Sherbrooke Universities) Département de génie civil, Université Laval, Quebec, pp 277-286.

Harkins, M.R. (1983). Alkali-aggregate Reaction: Minimising the Risk of Alkali-silica Reaction, Guidance Notes. Report of a Working Party. Cement and Concrete Association, Ref. 97-304, Wexham Springs, Slough, UK., 8 p.

Heijnen, W.M.M. (1992). Alkali-aggregate reactions in Netherlands. Proceedings of the 9th International Conference on Alkali-aggregate Reaction in Concrete, London, The Concrete Society, pp 432-439.

Hooper R, Matthews J D, Nixon P J, Thmoas M D A (2004) The introduction of BS EN fly ash and mitigating the risk of ASR in the UK. Proceedings of the 12th International Conference on Alkali Aggregate Reaction in Concrete, Beijing, pp 544-553.

Hopper R L, Nixon P J, Thomas M D A (2004) Considerations when specifying lithium admixtures to mitigate the risk of ASR. Proceedings of the 12th International Conference on Alkali Aggregate Reaction in Concrete, Beijing, pp 554-563.

JCI-AAR Committee (1992). Concrete test method for alkali-silica reaction (JCI AAR-3). Proceedings of the 9th International Conference on Alkali-aggregate Reaction in Concrete, London, The Concrete Society, pp 712-722.

Jensen, V. & Fournier, B. (2000). Influence of different procedures on accelerated mortar bar and concrete prism tests: assessment of seven Norwegian alkali-reactive aggregates. Proceedings of the 11th International Conference on Alkali-aggregate Reaction in Concrete, Quebec City, Centre de Recherche Interuniversitaire sur le Béton (CRIB) (Laval and Sherbrooke Universities) Département de génie civil, Université Laval, Quebec, pp 345-354.

Johnston, D. & Fournier, B. (2000). A kinetic-based method for interpreting accelerated mortar bar test (ASTM C1260) data. Proceedings of the 11th International Conference on Alkali-aggregate Reaction in Concrete, Quebec City, Centre de Recherche Interuniversitaire sur le Béton (CRIB) (Laval and Sherbrooke Universities) Département de génie civil, Université Laval, Quebec, pp 355-364.

Katayama, T. (2000) Alkali-aggregate reaction in the vicinity of Izmir, Western Turkey. Proceedings of the 11th International Conference on Alkali-aggregate Reaction in Concrete, Quebec City, Centre de Recherche Interuniversitaire sur le Béton (CRIB) (Laval and Sherbrooke Universities) Département de génie civil, Université Laval, Quebec, pp 365-374.

Lane, D.S. (2000a). Alkali-silica reactivity in Virginia, USA: occurrences and reactive aggregates. Proceedings of the 11th International Conference on Alkali-aggregate Reaction in Concrete, Quebec City, Centre de Recherche Interuniversitaire sur le Béton (CRIB) (Laval and Sherbrooke Universities) Département de génie civil, Université Laval, Quebec, pp 385-394.

Lane, D.S. (2000b). Preventive measures for alkali-silica reactions used in Virginia, USA. Proceedings of the 11th International Conference on Alkali-aggregate Reaction in Concrete, Quebec City, Centre de Recherche Interuniversitaire sur le Béton (CRIB) (Laval and Sherbrooke Universities) Département de génie civil, Université Laval, Quebec, pp 693-702.

Larbi J, Modry S, Katayama T, Blight G, Ballim Y (2004) Guide to diagnosis and appraisal of AAR damage in concrete structures: the RILEM TC191-ARP approach. Proceedings of the 12th International Conference on Alkali Aggregate Reaction in Concrete, Beijing, pp 921-932.

Lee, C., Sheu, S.W., Chen, K.C., Ko, J.L. & Rau, C.C. (2000) Field AAR inspection for the four harbors in Taiwan. Proceedings of the 11th International Conference on Alkali-aggregate Reaction in Concrete, Quebec City, Centre de Recherche Interuniversitaire sur le Béton (CRIB) (Laval and Sherbrooke Universities) Département de génie civil, Université Laval, Quebec, pp 869-878.

Lee, C., Shieh, W.K., lou, I.J. & Sheu, S.W. (2000) Evaluation of the effectiveness of slag and fly ash in preventing expansion due to AAR in Taiwan. Proceedings of the 11th International Conference on Alkali-aggregate Reaction in Concrete, Quebec City, Centre de Recherche Interuniversitaire sur le Béton (CRIB) (Laval and Sherbrooke Universities) Département de génie civil, Université Laval, Quebec, pp 703-712.

Li P X, Yang H Q (2004) Research on the activity of granite aggregate. Proceedings of the 12th International Conference on Alkali Aggregate Reaction in Concrete, Beijing, pp 355-361.

Lindgård, J. & Haugen, M. (2000) A review of the Norwegian experience with the correlation between results obtained by use of petrographic analysis and the accelerated mortar bar test. Proceedings of the 11th International Conference on Alkali-aggregate Reaction in Concrete, Quebec City, Centre de Recherche Interuniversitaire sur le Béton (CRIB) (Laval and Sherbrooke Universities) Département de génie civil, Université Laval, Quebec, pp 405-414.

Livesey, P. (1992). Alkali susceptibility of UK aggregates. Proceedings of the 9th International Conference on Alkali-aggregate Reaction in Concrete, London, The Concrete Society, pp 614-621.

Michel, B., Gnagne, C., Thiebaut, J., Wackenheim, C. & Maurin, B. (2000). Flint reactivity. Proceedings of the 11th International Conference on Alkali-aggregate Reaction in Concrete, Quebec City, Centre de Recherche Interuniversitaire sur le Béton (CRIB) (Laval and Sherbrooke Universities) Département de génie civil, Université Laval, Quebec, pp 71-80.

Mullick, A.K. & Wason, R.C. (2000). Comparison of different expansion tests to assess reactivity of concrete aggregates. Proceedings of the 11th International Conference on Alkali-aggregate Reaction in Concrete, Quebec City, Centre de Recherche Interuniversitaire sur le Béton (CRIB) (Laval and Sherbrooke Universities) Département de génie civil, Université Laval, Quebec, pp 425-434.

Mullick, A.K., Wason, R.C. & Sinha, S.K. (1992). Potential reactivity of quartzite aggregates containing strained quartz. Proceedings of the 9th International Conference on Alkali-aggregate Reaction in Concrete, London, The Concrete Society, pp 673-682.

Nixon, P.J. & Sims, I (1992). RILEM TC106 Alkali-aggregate Reaction - Accelerated tests interim report and summary of survey of national specifications. Proceedings of the 9th International Conference on Alkali-aggregate Reaction in Concrete, London, The Concrete Society, pp 731-738.

Nixon, P. & Sims, I. (1996). Testing Aggregates for Alkali-reactivity, Report of RILEM TC-106. Materials and Structures, vol. 29, No. 190, 1996, pp 323-334.

Nixon, P. & Sims, I. (2000). Universally accepted testing procedures for AAR the progress of RILEM Technical Committee 106. Proceedings of the 11th International Conference on Alkali-aggregate Reaction in Concrete, Quebec City, Centre de Recherche Interuniversitaire sur le Béton (CRIB) (Laval and Sherbrooke Universities) Département de génie civil, Université Laval, Quebec, pp 435-444.

Powers, L.J., (1999). Developments in alkali-silica gel detection, Concrete Technology Today. PL991, Portland Cement Association, http://www.portcement.org/pdf_files/PL991.pdf.

RILEM (2000). RILEM TC 106-AAR: Alkali-aggregate reaction, Materials and Structures, Vol. 33, June 2000, pp 283-293.

RILEM (2001). AAR-4-Detection of Potential alkali-Reactivity - Accelerated method for aggregate combinations and concrete mix design's using concrete prism. Internal Report RILEM/TC-ARD/01/20, 18 p.

RILEM (2003). Survey of AAR test methods in use (10^{th} edition), Internal Report RILEM/TC-ARP/02/15, 5 p.

Rogers, C., Grattan-Bellew, P.E., Doug Hooton, R., Ryell, J. & Thomas, M.D.A. (2000). Alkali-aggregate reactions in Ontario. Canadian Journal Civil Engineering, vol 27, http://www.irc.nrc-cnrc.gc.ca/fulltext/nrcc43940.pdf, pp 246 - 260.

Shrimer, F. and Jones, D.M. (2000). AAR in Southern British Columbia and Western Washington. Proceedings of the 11th International Conference on Alkali-aggregate Reaction in Concrete, Quebec City, Centre de Recherche Interuniversitaire sur le Béton (CRIB) (Laval and Sherbrooke Universities) Département de génie civil, Université Laval, Quebec, pp 463-472.

Sims, I., Smart, S. and Hunt, B. (2000). Practical petrography - The modern assessment of aggregates for AAR potential. Proceedings of the 11th International Conference on Alkali-aggregate Reaction in Concrete, Quebec City, Centre de Recherche Interuniversitaire sur le Béton (CRIB) (Laval and Sherbrooke Universities) Département de génie civil, Université Laval, Quebec, pp 493-502.

Smith I, Nixon P J, Marion A (2004) International collaboration to control alkali-aggregate reaction: the successful progress of RILEM TC 106 and TC 191-ARP. Proceedings of the 12th International Conference on Alkali Aggregate Reaction in Concrete, Beijing, pp 41-50.

Strang, F. (2000). The new Brunswick department of transportation's experience with alkali-silica reaction (ASR). Proceedings of the 11th International Conference on Alkali-aggregate Reaction in Concrete, Quebec City, Centre de Recherche Interuniversitaire sur le Béton (CRIB) (Laval and Sherbrooke Universities) Département de génie civil, Université Laval, Quebec, pp 503-512.

Strategic Highway Research Program (SHRP) (1996), Alkali-silica Reactivity, Technical Brief # 13. National Research Council, Washington DC, USA, http://www.cshrp.org/products/csbf.e13.pdf, 8 p.

Tamura, H., Takahashi, T. & Ohashi, M. (1992). Minimizing of alkali-aggregate reaction in concrete. Proceedings of the 9th International Conference on Alkali-aggregate Reaction in Concrete, London, pp 1035-1042.

The South African Department of Public Works (1993). Specification of Materials and Methods to be Used, http://www.publicworks.gov.za/docs/consultants/pw371.pdf, Pretoria, 26 p.

Thomas, M.D.A (2001). Using Silica Fume to Combat ASR in Concrete, http://www.icjonline.com/techpapers/2001/October/paper7/Thomas.pdf, 6 p.

Touma, W.E., Suh, C., Fowler, D.W., Carrasquillo, R.L. & Folliard, K.J. (2000). Alkali-silica reaction in Portland cement concrete: Testing procedures and mitigation methods. Proceedings of the 11th International Conference on Alkali-aggregate Reaction in Concrete, Quebec City, Centre de Recherche Interuniversitaire sur le Béton (CRIB) (Laval and Sherbrooke Universities) Département de génie civil, Université Laval, Quebec, pp 513-522.

Toutlemonde et al (2004) Extensive database for validating ASR modelling: a French contribution to the re-assessment of ASR-affected structures. Proceedings of the 12th International Conference on Alkali Aggregate Reaction in Concrete, Beijing pp 31-40.

Wigum, B.J., Hagelia, P., Haugen, M. & Broekmans, M.A.T.M.(2000). Alkali-aggregate reactivity of Norwegian aggregates assessed by quantitative petrography. Proceedings of the 11th International Conference on Alkali-aggregate Reaction in Concrete, Quebec City, Centre de Recherche Interuniversitaire sur le Béton (CRIB) (Laval and Sherbrooke Universities) Département de génie civil, Université Laval, Quebec, pp 533-542.

Wood, J.G.M. (2000). Comparison of field performance with laboratory testing: How safe and economic are current AAR specifications. Proceedings of the 11th International Conference on Alkali-aggregate Reaction in Concrete, Quebec City, Centre de Recherche Interuniversitaire sur le Béton (CRIB) (Laval and Sherbrooke Universities) Département de génie civil, Université Laval, Quebec, pp 543-552.

Tremblay C, Berube M A, Fournier B, Thomas M D, Stokes D B (2004) Performance of lithium-based products against ASR: application to Canadian reactive aggregates, mechanism, and test. Proceedings of the 12th International Conference on Alkali Aggregate Reaction in Concrete, Beijing, pp 668-677.

Hong Kong

Gilbert, S.T. & Tse W.L. (1994). Final Report on the Investigation of Cracks at Shek Wu Hui Treatment Plant. Geotechnical Engineering Office, Special Project Report SPR 9/94, 35 p.

Leung, W.C., Tse, W.L., Mak, C.S. & Gilbert, S.T. (1995). AR Potential of Volcanic Rocks from Anderson Road Quarries. Geotechnical Engineering Office, GEO Report No. 49, 78 p.

Leung, W.C., Shen, J.M., Lau, W.C. & Chan, C.Y. (2000) Testing aggregates for alkali-aggregate reactions in Hong Kong. Proceedings of the 11th International Conference on Alkali-aggregate Reaction in Concrete, Quebec City, Centre de Recherche Interuniversitaire sur le Béton (CRIB) (Laval and Sherbrooke Universities) Département de génie civil, Université Laval, Quebec, pp 395-404.

Liu, K.K. (2002). Studies on Alkali Aggregate Reactions in Concrete. Geotechnical Engineering Office, Discussion Note DN 1/2002, 36 p.

Read, A.S. & Anderson, G.M. (2000). Use of Volcanic Aggregate from Anderson Road Quarry in Concrete, Final Report on Stage 1 Testing, 12 p.

APPENDIX B

INTERNATIONAL PRACTICE OF ASR CONTROL FRAMEWORK

Australia

Aggregate Reactivity (3 classes)	+	Structure Class (3 classes)	→	Prevention Level (4 levels)

Prevention Levels:
- i) Preventive measures not needed
- ii) Limit alkali level
- iii) Use blended cements/SCM
- iv) Use alternative aggregate or mix with non-reactive aggregate

Note: SCM - Supplementary cementatious materials including pulverised fuel ash (PFA), ground granulated blast-furnace slag (GGBS) and silica fume.

Reference: Guirguis & Clarke (2000)

Canada

Aggregate Reactivity (3 classes)	+	Environment & Size of Elements (3 classes)	→	ASR Risk Level (4 levels)
ASR Risk Level	+	Structure Class (3 classes)	→	Prevention Level (5 levels)

Prevention Levels:

Level V:	Preventive measures not needed
Level W, X & Y:	Reject aggregates, or limit alkali content or add SCM to the prescribed extent
Level Z:	Reject reactive aggregate, or combine limiting alkali content and adding SCM

Reference: CSA (2000); Fournier, B., Bérubé., M.A.& Rogers, C.A. (2000); Malvar L.J. et al (2001); Touma W.E. et al (2001)

Denmark

Environment (3 classes)	+	Aggregate Size (2 sizes)	→	Tests and limits for accepting aggregates

Reference: Swamy R.N. (1992)

France

Environment (4 classes)	+	Structure Class (3 classes)	→	Prevention Level (3 level)

Prevention Levels:
A. Preventive measures not needed
B. Preventive measures: any one of
    Satisfactory track record of aggregate
    Satisfactory track record of concrete mix
    Alkali content below limit
    Add SCM
C. Use of non-reactive aggregate

Reference: Godart B. & Le Roux A. (1992), Touma W.E.et al (2001)

Germany

Aggregate Reactivity (3 classes)	+	Environment (3 classes)	→	Prevention Level (3 levels)

Prevention Levels:
1. Preventive measures not needed;
2. Use low-alkali cement;
3. Reject aggregate

Reference: Hobbs D.W. (1988)

Japan

Aggregate Reactive → Preventive Measures:
    Low alkali cement
    Limit alkali content
    SCM: GGBS, OPC/PFA cement

Reference: Hobbs D.W. (1988), Swamy R.N. (1992)

New Zealand

For normal* concrete	→	Limit alkali content to 2.5 kg/m^3		
Aggregate reactive				
For special* concrete Environment & Member size (3 classes)	+	Structure Class (3 classes)	→	Prevention Level (3 levels)

Prevention levels: Nil: preventive measures not needed
Low, Standard & Extraordinary: reject aggregate, or limit alkali content or add SCM to the prescribed extent.

Note:
Normal concrete: concrete producer designs mix to the specification of NZS 3104:2003 and is responsible for the workability and strength of the concrete produced.
Special concrete: the designer imposes specification additional to NZS 3104:2003 and is to agree with the concrete producer on acceptance criteria and quality assurance.

Reference: St John D.A. (1992), Swamy R.N. (1992), Cement and Concrete Association of New Zealand (2003).

RILEM

Structure class (3 classes)	+	Environment (3 classes)	→	Prevention Level (4 levels)

Prevention levels:
- P1 Preventive measures not needed
- P2 one of the preventive measures
  - M1: restrict alkali content of the pore solution (extent depends on aggregate reactivity)
  - M2: avoid the presence of a critical amount of reactive silica
  - M3: maintain concrete in a sufficiently dry state
  - M4: modify property gel (using lithium nitrate)
- P3 in addition to P2, design concrete to resist the aggravating factor
- P4 combination of two of the preventive measures of P2

Reference: RILEM (2005a)

UK

Aggregate Reactivity (3 classes)	→	Preventive measures: Limit alkali content of concrete or add SCM to various degrees.

Reference: Hobbs D.W. (1988); Hobbs D.W. (2000); Nixon, P. & Blackwell, B. (2000); Poole, A.B. et al (2000); West G. (1996); Concrete Society (1999)

USA

Aggregate Reactive	→	Preventive Measures Use SCM: Class F PFA, Class C PFA, class N pozzolan, GGBS, Silica fume Use low alkali cement Add lithium nitrate

Reference: Jawed I. (1992), Malvar L.J. et al (2001), Touma W.E. et al (2001)

Summary

- There appears to be three general forms of framework.

- The simplest form is that of Japan and the USA in which aggregates are classified as innocuous or reactive; and preventive measures are prescribed for use with reactive aggregates.

- The second and the third forms take into account the nature of the structures to be constructed and the environment they are in, for prescribing preventive actions.

- In the second form, represented by Australia, Canada and Germany, consideration starts with the reactivity of the aggregate to be used.

- In the third form, represented by France, New Zealand and RILEM, aggregate reactivity is considered only in the choice of preventive measures.

- The second form works better for a place where innocuous aggregates are not common such that the focus is on how to make reactive aggregates work. The third form is for places with some reactive aggregates, so that the designer could decide whether and how to use reactive aggregates to suit the requirement of his project.

- The third form of framework appears to suit Hong Kong better.

APPENDIX C

INTERNATIONAL PRACTICE ON CLASSIFICATION OF STRUCTURES

Country	Structure Class	Classification
RILEM	3 Classes: S1 - low risk S2 - normal risk S3 - high risk	 - Consequence of deterioration small or negligible: Non load-bearing elements inside buildings, temporary or short service life structures (likely design life <50 years); easily replaceable elements, and most domestic structures - Some safety, economic or environmental consequences of major deterioration: Most building and civil engineering structures, normally designed for service life of 50-100 years. - Serious consequence if any deterioration: Long service life or highly critical structures where the risk of deterioration from AAR damage is judged unacceptable, e.g. nuclear installations, dams, tunnels, exceptionally important bridges or viaducts and structures retaining hazardous materials
Australia	3 Classes: Low Moderate High	 - Structures with higher concrete strengths exposed to long periods of high humidity are particularly in a higher class while low strength concretes are in a low class. - Guidelines recommend that concrete of 25 MPa or less are considered to be for low risk structures
Canada	3 Classes: Class 1 Class 2 Class 3	 - Temporary elements with an expected or desirable service life of 5 years or less - Concrete elements which have an expected life of from 5 to 50 years - Concrete elements with a service life of 50 years or more. This class also includes all structures for which a major repair would be either impossible or very expensive
France	3 Classes: Low or slight risk of AAR acceptable Risk of AAR barely acceptable Risk of AAR unacceptable	Examples: - Non load-bearing elements located inside buildings, (temporary structures) - Most civil engineering structures - Exceptional bridges and tunnels (buildings and reactors of nuclear power plants)

Country	Structure Class	Classification
New Zealand	3 Classes:	
	S1	Some deterioration from ASR is acceptable e.g. non-load bearing elements inside buildings, temporary structures. Includes elements on which deterioration would be detected during normal use and inspection of the structure and that are easy and cheap to replace. These elements are likely to be designed for service life less than 50 years.
	S2	Minor ASR and resulting cosmetic cracking acceptable e.g. most buildings and civil structures (e.g. bridges). Includes elements on which deterioration might or might not be detected during normal inspection but where remediation of the element or structure would be possible if necessary. These structures would normally be designed for service life 50 or 100 years.
	S3	No ASR damage is acceptable, even if only cosmetic e.g. dams, tunnels and other major or prominent civil structures, structures retaining hazardous materials, nuclear installations, architectural finishes such as F6. Includes critical elements on which deterioration would not be detected in normal inspection and where remediation of the element structure would not be practical. These structures would normally be designed for service life 100 years or longer.

APPENDIX D

INTERNATIONAL PRACTICE ON CLASSIFICATION OF ENVIRONMENT

Country	Environment Class	Explanation/Clarification
Read & Anderson (2002) suggested	3 Classes: Dry Exposed Severe	 - Likely to remain dry with only a low risk of wetting, e.g. air-conditioned building interior - subject to wet conditions such as rainfall or natural ground water - wet conditions with salt or chemical contamination such as marine exposure
RILEM	3 Classes: E1 - protected from extraneous moisture E2 - exposed to extraneous moisture E3 - exposed to extraneous moisture plus aggravating factors	 - Internal concrete within buildings; external concrete protected from the atmosphere, e.g. by cladding - Internal concrete in buildings where humidity is high; e.g. laundries, tanks, swimming pools; concrete exposed to external atmosphere or to non-aggressive ground; internal mass concrete with a least dimension of 1 m or more - Internal or external concrete exposed to de-icing salts; concrete exposed to seawater or salt spray; concrete exposed to freezing and thawing whilst wet; concrete subjected to prolonged elevated temperatures whilst wet
Canada	3 Classes: Non-massive and dry Massive and dry All concrete exposed to humid air, buried or immersed	 - a massive element has a least dimension of one meter or more - a dry environment corresponds to ambient average relative humidity condition < 60%, normally found in buildings - a risk of ASR exists for massive concrete elements in a dry environment because the internal concrete has a high relative humidity - a non-massive concrete element constantly immersed in sea water does not present a higher risk of ASR than a similar element exposed to humid air, buried in the ground, or immersed in pure water because the alkali concentration of sea water (30 g/L NaCl => 0.51 M NaCl or Na) is lower than the alkali concentration of the pore solution of most concretes, while the penetration of Cl ions is usually limited to a few centimetres

Country	Environment Class	Explanation/Clarification
Denmark	3 Classes: Passive environment Moderate environmental Aggressive environment	 - comprises dry, non-aggressive environment, i.e. particularly an indoor climate - comprises moist, non-aggressive outdoor and indoor environment, and flowing or standing fresh water. - comprises environment containing salt or flue gases, seawater or brackish water.
France	4 Classes: Class 1 Class 2 Class 3 Class 4	Type of environment - dry or only slightly damp (RH < 80%) - damp to wet or in contact with water - wet with frost and de-icing salts - maritime environment
Germany	3 Classes: D - Dry M - Moist M+A - Moist plus an external supply of alkali	Examples - interior components of buildings - externally exposed components - concrete components exposed to seawater or de-icing salts
Ireland	2 Classes: Class 1 Class 2	 - Relative humidity remains below 80% except for short periods through the life of the structure, or, the structure is protected from severe exposure to moisture or the elements in its working environment - the opposite of Class 1

Country	Environment Class	Explanation/Clarification
New Zealand	3 Classes:	
	E1	Non-massive (1) and dry (2) e.g. a damp-proofed floor in dry service conditions
	E2	Massive and dry (2,3); all concrete exposed to humid air, condensation, rain, run-off, groundwater (4), or other sources of moisture. e.g. building facades, foundations, concrete elements in a building enclosing a swimming pool or laundry, water-retaining structures.
	E3	Concrete exposed to external moisture and to aggravating factors such as freezing and thawing, wetting and drying in a marine environment or prolonged elevated temperatures. e.g. concrete in the splash zone of a marine structures; concrete exposed to moisture and elevated temperatures such as a cooling tower or chimney
	Notes: (1) A massive element has a least dimension of 0.5 m or more (2) A dry environment corresponds to an ambient average relative humidity condition lower than 60% (normally only found inside buildings) and no exposure to external moisture sources. (3) A risk of alkali-silica reaction exists for massive concrete elements in a dry environment because the internal concrete may still have a high relative humidity. (4) A non-massive concrete element constantly immersed in sea water does not present a higher risk of ASR than a similar element exposed to humid air, buried in the ground, or immersed in pure water, because the alkali concentration of sea water (30 g/l NaCl, i.e. 0.57 M NaCl or Na) is lower than the alkali concentration of the pore solution of most concretes, and the penetration of Cl^- ions is usually limited to a few centimetres.	

APPENDIX E

INTERNATIONAL PRACTICE ON CLASSIFICATION OF ASR REACTIVITY

Country	Classification	Testing Method and recommended Limits
Read & Anderson (2002) suggested	5 Classes: Low Medium High Very High Extreme	AMBT to RILEM TC 106-2 (AAR-2) Up to and including 0.10% expansion Up to and including 0.20% expansion Up to and including 0.30% expansion Up to and including 0.40% expansion Greater than 0.40% expansion
RILEM	3 Classes: Class I: very unlikely to be alkali-reactive Class II: potentially alkali-reactive or alkali-reactivity uncertain Class III: very likely to be alkali-reactive	AMBT - criteria for interpretation to be finalised, tentatively* < 0.1%: non reactive > 0.2%: reactive, suggests that it is not currently possible to provide interpretative guidance for results in the range of 0.1% - 0.2%; for all practical purposes in the absence of additional local experience, aggregate yielding results in this range will need to be regarded as being potentially alkali-reactive. CPT - criteria for interpretation to be finalised, tentatively* < 0.05%: non reactive > 0.1%: reactive, suggests that it is not currently possible to provide interpretative guidance for results in the range of 0.05% - 0.10%; and, for all practical purposes in the absence of additional local experience, aggregate yielding results in this range will need to be regarded as being potentially alkali-reactive. Accelerated concrete prism test - suggested tentatively <0.03% at 15 weeks: non-reactive.
	* Note: Classification quoted from Sims et al (2004). RILEM (2005a) described a 3-tier classification system based on the alkali thresholds of aggregates.	

Country	Classification	Testing Method and recommended Limits
Canada	3 Classes Non Reactive Moderately Reactive Highly Reactive	Petrographic Examination (ASTM C295) No limit, regarded as essential to interpreting results of other observations AMBT (CSA A23.2-25A) Expansion < 0.15%: Non-reactive (0.1% for limestone and some other aggregates) Expansion > 0.15%: Highly Reactive (Note: AMBT was not considered suitable for distinguishing between moderate and highly reactive aggregates. In the absence of CPT data, aggregates that produces > 0.15% expansion at 14 days in the AMBT (0.1% for limestone) are classified as highly reactive) CPT (CSA A23.2-14A) Definitive test - use as a ‘pass or fail’ criterion Expansion < 0.04%: Non-reactive Expansion 0.04 - 0.12%: Moderately Reactive Expansion > 0.12%: Highly Reactive

Country	Classification	Testing Method and recommended Limits
Denmark	3 Classes: Class P: for use in passive environment Class M: for use in moderate environments Class A: for use in aggressive environments	Classification of Sand: Petrographic examination using point-count method on thin sections (TI-B 52) - Mandatory Volume of reactive flint Class P: not limited Class M: max 2% Class A: max 2% Mortar bar expansion (TI-B 51) @ 8 weeks Class P: not limited Class M: max 0.1% Class A: max 0.1% Classification of Coarse Aggregate Petrographic examination using point-count method on thin sections (TI-B 52) - Mandatory Amount of reactive aggregate is limited by the allowable amount of particles with density < 2400 kg/m^3. This value is determined on 10% of the flint with porous crust. Class P: not limited Class M: max 5% Class A: max 1% Adsorption (%) Class P: not limited Class M: max 2.5% Class A: max 1.1%

Country	Classification	Testing Method and recommended Limits
France	3 Classes: NR: non reactive PR: potentially reactive PRP: potentially reactive with a pessimum effect	Classification proceeds through petro-mineralogical analysis which produces a "pre-diagnostic" through the evaluation of the reactive silica content. This pre-diagnostic is then controlled with one of the following 5 tests, except when the flint content of the sample exceeds 50%. In this particular case, only the first two tests should be used, as they are the only tests to detect the pessimum effect. (1) Chemical kinetic test (XP P 18-589) (2) Microbar test (XP P 18-588) measure relative expansion of micro mortar prism (1x1x4cm) with 3 cement/aggregate ratios (c/g): c/g = 2, 5 and 10. Classified PR when one of the expansion reading > 0.11% Classified PRP when the value at c/g=5 > that of c/g=2 (3) Autoclave Test (XP P 18-590) measure relative expansion of mortar prism (4x4x16cm) @ 18 hours. Classified PR when > 0.15% (The above 3 tests are rapid tests, used as screening tests. When PR assessment is obtained, a reference test of the following 2 tests should be applied.) (4) Mortar bar (XP P 18-585) (5) Concrete prism (XP P 18-587) Sand sample: > 0.1% @ 6 months: Potentially Reactive (PR) Gravel sample: > 0.1% @ 8 months: Potentially Reactive (PR)
Germany	3 Classes: E1: inert EII: limited use with respect to ASR EIII: deleteriously reactive	Classification is based on the quantities of opal sandstone and active flint obtained from tests.

Country	Classification	Testing Method and recommended Limits
Japan	2 Classes Innocuous Reactive	 Concrete Method (JASS 5NT-603, JCI AAR-3) < 0.1% @ 6 months: innocuous ≥ 0.1% @ 6 months: reactive Rapid Test (JIS A 1804) Innocuous if one of the following three conditions applies: (1) ultrasonic pulse velocity ≥ 95%, (2) relative dynamic modulus of elasticity ≥ 85%, (3) length change < 0.1% Chemical method (JIS A 1145) Mortar bar method (JIS A 1146) Appendix 7 & 8 of JIS A 5308 ready-mixed concrete
Netherlands	3 Classes: Under critical Above critical Critical	 Petrographic examination - Under Critical: contain low amount of reactive components such that no harmful ASR can occur - Above critical: contain high amount of reactive components such that no harmful ASR can occur - Critical: contain the amount of reactive components that harmful ASR can occur

Country	Classification	Testing Method and recommended Limits
New Zealand	2 classes Innocuous Reactive	(1) Petrographic Examination Recommended Step 1 for screening reactive aggregate by determining the mineral composition. If the aggregate contains no potentially reactive components, AAR need not be considered further. If it does contain potentially reactive components, even as contaminants, either assume the aggregates to be reactive or carry out further investigation. (2) Field Data Recommended Step 2. If aggregate contains potentially reactive material, assess the aggregate's reactivity from existing test data or field experience (3) Chemical Test (ASTM C289) Recommended Step 3. If neither existing test data nor field experience are available, assess its reactivity by ASTM C289. If ASTM C289 tests show the rock to be non-reactive, AAR need not be considered further. If the aggregate is shown to be deleterious or potentially deleterious, either assume that it is reactive or carry out mortar/concrete tests to establish its likely reactivity in concrete. (4) Mortar or concrete tests Recommended Step 4. If mortar or concrete tests show the rock to be non-reactive, AAR need not be considered further. If the aggregate is shown to be deleterious or potentially deleterious, then preventive measures such as limiting alkali limit to 2.5 kg/m^3 should be implemented.

Country	Classification	Testing Method and recommended Limits
Norway	3 Classes: Innocuous Deleterious but slowly expanding Deleteriously reactive and rapid expanding	Petrographic analysis by point counting (Norwegian method) potentially reactive rock types < 20%: innocuous potentially reactive rock types > 20%: alkali reactive AMBT (South African NBRI AMBT) Expansion after 14 days (i) ≤ 0.10% → innocuous (ii) between 0.10% and 0.25% → deleterious but slowly expanding (iii) ≥ 0.25% → potentially deleteriously reactive and rapid expanding
UK	3 Classses: Low Reactivity Normal Reactivity High Reactivity	Petrographic Examination (BS 7943:1999) CPT (BS DD 218, now replaced by BS 812-123 (1999)) - Expansive: if > 0.2% expansion after 12 months - Possible Expansive: if between 0.1% and 0.2% - Probably non-expansive: if between 0.05% and 0.1% - Non-expansive: if < 0.05%
USA	2 classes: Innocuous Potentially deleterious	AMBT (ASTM C 1260) Expansion after 14 days > 0.08-0.1%: potentially deleterious < 0.08-0.1%: innocuous (0.08% for metamorphic aggregate and 0.1% for all other aggregates) CPT (ASTM C 1293) Expansion after 1 year > 0.04%: potentially deleterious < 0.04%: innocuous

Summary

The class limits for various counties could be summarized as follows.

Country	Acc. mortar bar*	Concrete prism*	Petrography	Field performance
Read et al [+]	---0.1%---0.2%---			Yes
RILEM	---0.1%---0.2%---	---0.05%---0.10%---	Yes	Yes
Canada	-----0.15%-----	---0.04%---0.12%---	Yes	Yes
Denmark	Non-standard tests		Yes	
France	Non-standard tests		Yes	Yes
Japan	Non-standard tests			Yes
Netherlands	Non-standard tests		Yes	
Norway	---0.1%---0.25%---		Yes	
UK		---0.05%---0.1%-----	Yes	
USA	-----0.1%-----	-----0.04%-----	Yes	

Legend:

* ---0.1%---0.2%---: The first figure denotes the limit for the class of non-reactive rock; the second figure denotes that for the lower class of reactive rock

-----0.1%-----: The figure denotes the limit for the class of non-reactive rock

\+ Read & Anderson (2002): It proposed a five-tier classification for Hong Kong

- Two-tier and three-tier classification systems are common.
- France and the Netherlands are special in having a class of aggregate that is non-reactive when it contains a high proportion of reactive elements (pessimum effect; above critical).
- Of the countries that use standard AMBT and CPT tests for classification, the limit for classifying non-reactive rock is 0.1% expansion after 14 days and 0.04/0.05% expansion after 1 year respectively. Beyond these limits, the aggregates are taken as potentially reactive.
- Where a medium ‘potentially reactive’ class is set, the upper limit of the class is either 0.20 (RILEM) or 0.25 (Norway) for AMBT and 0.10 (RILEM) or 0.12 (Canada) for CPT. Canada regarded AMBT as not precise enough for setting a medium class of reactivity.
- Read and Anderson (2002) followed the RILEM limits for the medium class of reactivity.
- Field performance is taken as the best method of distinguishing sources of reactive aggregates and innocuous aggregates.
- Petrographic examination is commonly adopted for accepting rock as non-reactive.
- RILEM (2005b) contains information that could be interpreted to produce expansion limits for demarcating potentially reactive rock and reactive rock. This has to be calibrated against CPT results.

List of Test Standards Used in Various Countries

RILEM

Petrographical examination (AAR-1, previously called TC-106-1)
Ultra-accelerated (mortar bar) expansion test (AAR-2, previously called TC-106-2)
Concrete prism test (AAR-3, previously called TC-106-3)
Ultra-accelerated (60^{O}C) concrete prism test (AAR-4, previously called TC-106-4)

Australia

Accelerated mortar bar test for AAR assessment by Road and Traffic Authority of NSW (RTA T363)
Concrete prism test for AAR assessment by Road and Traffic Authority of NSW (RTA T364)
Mortar-bar test (AS 1141 section 38)
Chemical Test (AS 1141 section 39)

Canada

Potential expansively of aggregates (procedure for length change due to AAR in concrete Prisms) (CSA A23.2-14A)
Detection of ASR aggregate by accelerated expansion of mortar bars (CSA A23.2-25A)
Petrographic examination of aggregates for concrete (ASTM C 295)
Petrographic analysis adopted by The British Columbia Ministry of Transportation and Highways (BCH 1-17)

Denmark

Mortar bar expansion test in saturated sodium chloride solution (TI-B 51)
Petrographic thin-section point-counting method (TI-B 52)

France

Long-term, mortar accelerated expansion tests at 38ºC (XP P 18-585) - (mortar bar test)
Long-term, concrete accelerated expansion tests at 38ºC (XP P 18-587) - (concrete prism test)
Ultra-accelerated expansion methods using mortar bars (XP P 18-588 and XP P 18-590) - Microbar test (XP P 18-588) and autoclave test (XP P 18-590)
Chemical kinetic test (XP P 18-589)

Japan

Concrete test method for alkali-silica reaction - concrete method (JASS 5NT-603, JCI AAR-3)
Chemical method (JIS A 1145)
Mortar bar method (JIS A 1146)
Methods of test for production control of concrete - method of rapid test for identification of the alkali reactivity of aggregates (JIS A 1804)

New Zealand

(Follows ASTM Testing Standards)

UK

Petrographic examination of aggregates (BS 812, Part 104)
Concrete Test (BS 812, Part 123:1999, replacing BS DD 218)

USA

Mortar-bar method (ASTM C 227)
Chemical method (ASTM C 289)
Petrographic examination of aggregates for concrete (ASTM C 295)
Accelerated detection of potentially deleterious expansion of mortar bars due to ASR (ASTM C 1260, AASHTO T 303): (Accelerated mortar bar method)
Concrete aggregates by determination of length change of concrete due to ASR (ASTM C 1293): (Concrete prism test)

APPENDIX F

INTERNATIONAL PRACTICES OF PREVENTIVE MEASURES AGAINST ASR

(See Appendices B to E for background information
on the control frameworks in which the measures are used)

Australia

Prevention Level	Aggregate Reactivity	Structure Class	Preventive Measures
1	Slow/mild	Low	Preventive measures not needed
2	Substantial	Low	Limit alkalis to 2.8 Kg/m³, or Use blended cements/SCM *[1]
	Slow/mild	Moderate	
3	Substantial	Moderate	Use blended cements/SCM *[1]
	Slow/mild	High	
4	Substantial	High	Use alternative aggregate, or If alternative aggregate is not available, assess proposed mixes and modify mix until the result is acceptable

Note:

1. Cement and Concrete Association of Australia (1996) recommends that silica fume should comprise at least 10% of the total binder content by mass to ensure minimising ASR damages)

Canada

Prevention Level	Aggregate Reactivity	Environment & Element Size *1	Structure	Preventive Measures
V	Non Reactive	All Classes	All Classes	Accept the proposed aggregate without any preventive measure but periodically ensure that the reactivity of the aggregate extracted has not changed
	Moderately Reactive	ND		
		MD	< 5 years	
		H		
	Highly Reactive	ND		
		MD		
W	Moderately Reactive	MD	5-50 years	<u>Mild preventive action</u> - use one of the following: (W1) Reject the aggregate, or (W2) Limit the alkali content to < 3.0 Kg/m^3 *2 (W3) Use SCM, Table B-2
	Highly Reactive	ND		
		H	< 5 years	
X	Moderately Reactive	MD	> 50 years	<u>Moderate preventive action</u> - use one of the following: (X1) Reject the aggregate, or (X2) Limit the alkali content to < 2.4 Kg/m^3, or (X3) Use SCM, Table B-2
		H	5-50 years	
	Highly Reactive	ND	> 50 year	
		MD	5-50 years s	
Y	Moderately Reactive	H	> 50 years	<u>Strong preventive action</u> - use one of the following: (Y1) Reject the aggregate, or (Y2) Limit the alkali content to < 1.8 Kg/m^3, or (Y3) Use SCM, Table B-2
	Highly Reactive	MD		
		H	5-50 years	
Z	Highly Reactive	H	> 50 years	<u>Exceptional preventive action</u> - use one of the following: (Z1) Reject the aggregate, or (Z2) Use <u>both</u> Y2 and Y3

Note:

*1: ND = non-massive and dry; MD = Massive and dry; H = All concrete exposed to humid air, buried or immersed

*2: The limit is that due to the Portland cement, in Na_2O equivalent = Na_2O + (0.658 x K_2O)

Table: Use of Supplementary Cementing Materials for Counteracting ASR

Type of SCM	Total Alkali Content of SCM *[1] (% Na2Oe)	Chemical Composition Requirement (% oxides)	Cement Replacement (% by mass) *[2]		
			Prevention Level W	Prevention Level X	Prevention Level Y & Z
Fly Ash	< 3.0	CaO < 8%	≥ 15	≥ 20	≥ 25
		CaO = 8-20%	≥ 20	≥ 25	≥ 30
		CaO > 20%	*[3]	*[3]	*[3]
	3.0 - 4.5	CaO < 8%	≥ 20	≥ 25	≥ 30
		CaO = 8-20%	≥ 25	≥ 30	≥ 35
		CaO > 20%	*[3]	*[3]	*[3]
	> 4.5	*[3]			
Blast Furnace Slag	< 1.0 *[2]	None	≥ 25	≥ 35	≥ 50
Silica Fume	< 1.0 *[2]	None	≥ 2.0 x alkali content *[4]	≥ 2.5 x alkali content *[4]	≥ 3.0 x alkali content *[4]
Natural Pozzolans	Natural pozzolans that meet the requirements of CSA A23.5 may be used provided that their effectiveness in controlling expansion due to ASR is demonstrated according to CSA A23.2-28A				
Ternary Blends	When two, or more, SCMs are used together to control ASR, the sum of the parts of each SCM is ≥ 1. For example, when silica fume and slag are combined, the silica fume level may be reduced to one third of the minimum silica fume level given in Table B-2 provided that the slag level is at least two thirds of the minimum slag level.				

Note:

1: Na_2O equivalent = sodium oxide equivalent = Na_2O + (0.658 x K_2O)

2: The total alkali content of the concrete mixture (cement + any SCMs) should be < 1.0 % Na_2Oe

3: Blast furnace slag and silica fume with alkali contents >1.0 % Na_2Oe, and fly ash with alkali contents > 4.5% Na2Oe and/or with CaO contents > 20% Na_2Oe may be used as SCM when their effectiveness is demonstrated in accordance with CSA A23.2-28A. Test results have indicated that higher alkali fly ashes (but not high CaO ashes), when used in large quantities (e.g., > 50% as cement replacement by mass), can reduce expansion to an acceptable level.

4: The minimum level of silica fume (as a % of cementitious material content) is calculated on the basis of the alkali content of the concrete, but in cases where silica fume is the only SCM to be used, the silica fume content should be > 7.0% by mass

5: Blended cements may be used provided that the proportions of the supplementary cementing materials in the blend meet the requirements of Tables B-1 and B-2.

France

Prevention Level	Structure Class *[1]	Environment *[2]	Preventive Measures
A	I:	All classes	Nil
	II	1	
B	II	2, 3 or 4	Use non-reactive aggregates, or Use a proven concrete design including proportion and sources of constituents, or Limit alkali content to 3 kg/m^3, or Add SCM
C	III	All classes	Use non-reactive aggregates

Note:

1. Structure classes: I = low or slight risk of ASR acceptable; II = Risk of ASR barely acceptable; III = Risk unacceptable
2. Environment classes: 1 = Dry or only slightly damp (RH < 80%); 2 = Damp to wet or in contact with water; 3 = Wet with frost and de-icing salts; 4: Maritime Environment

Germany

Prevention Level	Aggregate Reactivity *[1]	Environment *[2]	Preventive Measures
1	EI	All classes	None *[3]
	EII	D, M	
	EIII	D	
2	EII	M+A	Low-alkali cement *[4]
	EIII	M	
3	EIII	M+A	Replacement of aggregates

Note:

1. Aggregate reactivity: E1 = inert; EII = limited use with respect to ASR; EIII = deleteriously reactive.
2. Environment classes: D = Dry; M = Moist; M+A = Moist plus an external supply of alkali
3. In addition, if an approved admixture is used for classes EII structure in M environment, EII in M + A and EIII in M, then
   - (a) its mass should not exceed 2% of that of the cement
   - (b) the cement content should not exceed 400 Kg/m^3
   - (c) its alkali content expressed as equivalent sodium oxide should not be more than 8.5% by mass
4. For classes EII in M + A and EIII in M, the risk of cracking is minimized by
   - (d) Use of a ‘cement’ with a low effective alkali content
   - (e) Limit the cement content to 500 Kg/m^3
   - (f) Prohibit the use of mix water containing high contents of alkali

Japan

Preventive Measures

(a) Use non-reactive aggregate.

(b) Use of low alkali Portland cement (cement containing less than 0.6% by mass of equivalent sodium oxide)

(c) Limiting the maximum alkali content of the concrete to 3.0 Kg/m³ when a Portland cement with alkali content greater than 0.6% by mass is used.

(d) Use of an appropriate blended cement, such as blast-furnace slag cement type B or type C to JIS R 5211. Type B contains slag content of 30-60% and type C of 60-70% by mass.

(e) Use of type B or type C OPC/PFA cement to JIS R 5213. Type B contains between 10 and 20% by mass of PFA and type C 20-30% by mass. The total alkali content of the PFAs in use in Japan range from 0.6 to 3.1% by mass.

New Zealand

For Normal Concrete, limited alkali content of concrete to 2-5 kg/m^3 if aggregate is reactive.

For Special Concrete

Prevention Level	Structure Class *[1]	Environment *[2]	Preventive Measures
Nil	S1	E1	<u>No special precautions</u> are needed.
Low	S1	E2, E3	<u>Mild preventive action</u> - one of the following: L1: reject the aggregate, or L2: limit the alkali content of the concrete to < 3.0 kg/m^3 Na2O eq, or. L3: use SCM *[3].
	S2:	E1	
Standard	S2	E2, E3	<u>Standard preventive action</u> - one of the following: N1: reject the aggregate, or N2: limit the alkali content of the concrete to < 2.5 kg/m^3 Na2O eq, or N3: use SCM *[3].
	S3	E1	
Extraordinary	S3	E2, E3	<u>Exceptional preventive action</u> - one of the following: X1: reject the proposed aggregate, or X2: limit the alkali content of the concrete to < 1.8 kg/m^3 Na2O eq, or X3: use SCM *[3].

Note:

1. Structure classes: S1 = Some deterioration from ASR is acceptable; S2 = Minor ASR and resulting cosmetic cracking acceptable; S3 = No ASR damage is acceptable, even if only cosmetic
2. Environment classes: E1 = Non-massive & Dry; E2 = Massive & Dry; E3 = Concrete exposed to external moisture and to aggravating factors.
3. Where SCM is added to concrete to protect against ASR, the level of cement replacement will depend on the SCM used. Approximate replacement levels needed to minimise ASR damage are:
   - at least 8% for silica fume and geothermal silica;
   - At least 15% for diatomite and metakaolin;
   - More than 25% for pumicite and fly ash (high calcium fly ashes require an even higher replacement level); and
   - More then 50% for blast furnace slag.

RILEM

Prevention Level	Structure *[1]	Environmental *[2]	Preventive Measures *[3, 4]
P1	S1	All Classes	No special precautions
	S2	E1	
P2	S2	E2	One of the following measures: M1: restrict the alkalinity of the pore solution. M2: avoid the presence of a critical amount of reactive silica M3: reduce the access of moisture and maintain the concrete in a sufficiently dry state M4: modify the properties of any gel such that it is non-expansive
	S3	E1	
P3	S2	E3	P2 + designing concrete to resist the aggravating factor, e.g. seawater.
P4	S3	E2, E3	M2, or a combination of two of M1, M3 and M4

Note:

1. Structure class: S1 = Consequence of ASR is small or negligible; S2 = Some consequences if major ASR deterioration; S3 = Serious consequences if any ASR deterioration.
2. Environment class: E1 = Protected from extraneous moisture; E2 = Exposed to extraneous moisture; E3 = Exposed to extraneous moisture plus aggravating factors.
3. Preventive measures: M1 includes the use of low alkali cement and SCM; M4 is by adding lithium nitrate solutions.
4. Alkali limit and SCM depend on reactivity of aggregate as follows.

Aggregate reactivity	Alkali limit (kg/m^3 Na_2Oeq)
Low	None required
Medium	Typically 3.0 or 3.5
High	Lower limit, e.g. 2.5

Note: reactivity classified by alkali threshold, not AMBT or CPT.

Aggregate reactivity	recommended minimum proportions for reference, in % by mass of total cementitious material	
	Low lime PFA	GGBS
Low	-	-
Medium	25	40
High	40	50

Tentative: 8% silica fume (>85%SiO_2) or 15% Metakaolin (>45% SiO_2)

UK

Aggregate Classification	Alkali limit (Kg/m³) Portland cement alkali content, Na_2O_{eq} (%)		
	≤ 0.60	≤ 0.75	> 0.75
Low reactivity	Self-limiting	Self-limiting	≤ 5.0
Normal reactivity	Self-limiting	≤ 3.5	≤ 3.0
High reactivity	≤ 2.5	≤ 2.5	≤ 2.5

APPENDIX G

SUMMARY OF LOCAL EXPERIENCE ON ASR

Control Framework

Suspected alkali silica reaction (ASR) was first diagnosed in Hong Kong in 1991 (Wong & Koirala, 1992). Overseas experience was reviewed and a general control framework was introduced in 1994. The framework is described in WBTC 5/94. It prescribes the preventive measure of controlling the alkali content in concrete to 3.0kg/m^3. It is open on the policy of the use of reactive aggregates in concrete.

HKQAA operates the Quality Scheme for the Production and Supply of Concrete (QSPSC). The scheme requires that where new sources of aggregate are proposed, the aggregate should be tested before use for potential alkali reactivity. The test is to be ASTM C289 (chemical test) or other recognized testing methods. The chemical test has been found to be ineffective in screening alkali reactivity of aggregate in Hong Kong.

MTRC requires that concrete for its structures is limited to 3 Kg/m^3 in alkali content, uses aggregate which AMBT expansion at 14 days is less than 0.15%, and contains no river sand. It also accept up to 40% of PFA in the concrete.

Read & Anderson (2002) proposed a control framework. The framework is of the second form discussed in Appendix B: it starts with the reactivity of the aggregate in hand and then shows how to use the aggregate for the particular combination of the service environment and the nature of the structure to be constructed.

Past Studies

Since the suspected case of ASR, the Public Works Laboratories (PWL) of the Geotechnical Engineering Office (GEO) started a series of trials on the accelerated mortar bar test (AMBT). GEO also carried out petrographic examinations on specimens of concrete recovered from sites of suspected ASR, as part of the studies on these cases. The results are published in Gilbert (1995), Sewell (1999), Sewell (2000), Campbell (2000), Liu & Chan (2000), Sewell & Campbell (2001), Liu & Tam (2002), and Sewell et al (2007).

Hong Kong constructed its first major sea crossings in the mid 1990s as part of the ports and airport projects. Stringent specifications were set on concrete properties to ensure durability. One of the contractors commissioned a study on Lamma Quarry that was to supply aggregates. The quarry owner commissioned more studies when a part of the quarry face was found to have materials that were potentially reactive.

China Light and Power Co Ltd (CLP) commissioned L G Mouchel & Partners (Asia) and Taywood Engineering Limited to coordinate a study between 1988 and 2000 on the use of pulverized fuel ash (PFA) produced by CLP for the production of concrete and the properties of the resulting concrete. It included full-scale field studies at the ash lagoon at Tseng Tsui, simulated field studies and laboratory testing of 43 representative concrete mixes. PFA was introduced in the form of either blended cement or additions to the mixes. The PFA content ranged from 0 to 70% of the total cementitious materials; the rest being normal cement. The concrete mixes were used to cast seawall blocks from which samples could be cored at various time later for testing for comparison with laboratory specimens. The study was reported in Mouchel and Taywood (1990) and CLP Power (2002). The observation of ASR cracks on some seawall blocks in year 11 (1999) provides information on field performance of the aggregate in respect of alkali reactivity. Sewell et al (2007) revealed the presence of relatively small portion of ASR, but with considerable delayed ettringite formation.

Liu et al (2004) reported a study on granite aggregates from four queries in Hong Kong and its neighbourhood. The study included petrographic examination and laboratories tests including AMBT and concrete prism tests. The aggregate from Lam Tei Quarry in Hong Kong appeared to be reactive. Lam Tei Quarry has been importing rock to supplement rock excavated there to produce aggregate; and the paper has not been specific on the source rock of the aggregate that was tested.

Granite has been the main rock type quarried for aggregates in Hong Kong. At Anderson Road Quarry, the quarry face is capped by volcanic rocks that are alkali reactive. The quarry owner commissioned a series of studies that are reported in Anderson & Read (2002) and Read & Anderson (2002).

In the following sections, information relevant to various sources of aggregates is described and analysed.

Aggregates of Various Sources

Lamma Quarry

Taywood Maunsell Ltd. (1993) studied fitness of aggregates from Lamma Quarry for the Kap Shui Mun Bridge and Ma Wan Viaduct. The study covered geological inspection of the quarry face, petrographic examination of 10 thin sections, chemical testing and gel-pat tests. The gel-pat test showed the aggregate to be potentially reactive but the chemical testing to ASTM C289 showed the aggregate to be marginally innocuous. Petrographic examination showed possibly reactive materials in the form of microcrystalline quartz in cataclasite along shear zones, as thin veins, and as intergrowths with feldspar.

Geomaterials Research Services Ltd. (1993a) reported a study of the rock types of the quarry, especially in respect of the variability and general quality of the rock as aggregates. Key to the study is the detailed mapping of one bench of the quarry face during which hand specimens and bulk rock samples were collected for examination. The study recommended further petrographic examination.

A total of 10 thin sections were subsequently produced for petrographic examination. The study was reported in Geomaterials Research Services Ltd. (1993b). The study recommended mortar tests to measure reactivity of the aggregate. There was no record of the mortar bar test having been conducted.

Geomaterials Research Services Ltd. (1993c) and Geomaterials Research Services Ltd. (1993d) reported further petrographic examinations of 18 and 3 thin-sections from rock specimens of the quarry. They confirmed knowledge of the nature and extent of potentially reactive materials in Lamma Quarry.

The aggregate for the field trial of CLP at Tseng Tsui Ash Lagoon came from Lamma Quarry. Cement of normal alkali content was used for casting the seawall blocks. Seawater was used to cure the concrete but freshwater was said to have been used for production.

In 1999, cracking of seawall blocks of PFA-free concrete was noticed. This was subsequently confirmed by petrographic assessment to be the result of alkali silica reaction, although clear evidence was reported from only one thin section. The results were recorded in a petrographic report compiled by M.A. Eden and verified by W.J. French, both of Geomaterials Research Services Ltd. The extent of field performance had not been systematically recorded but detailed inspection showed that concrete with 25% PFA content did not show signs of alkali reaction (CLP Power, 2002). Infilling of the core hole using normal cement mortar initiated ASR cracking around the hole; this showed that the aggregate was reactive and the original absence of ASR was due to PFA in the concrete.

The findings of the petrographic study reported by Sewell et al (2007) strongly suggested the participation of alkali-silica gel and secondary ettringite in the distress of the concrete seawall blocks at Tsang Tsui Ash Lagoon. 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, but the alkali-silica gel generally is much less abundant than fibrous crystalline material resembling ettringite. It was concluded that 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.

Granite Aggregates in General

Shear zones and veins present in Lamma Quarry are not uncommon among granite masses. Such features at other granite masses could also be alkali reactive. Unless a granite face is quarried specifically to avoid such features, the aggregates produced are likely to be contaminated by materials from the features and hence potentially reactive. This presumption is commensurate with field experience. Sewell and Campbell (2001) reported ASR at concrete anchor heads on a cut slope behind North Point Government School. The concrete comprised granite aggregate of unknown sources and cement of normal alkali content. The aggregate in the concrete was granite of unknown origin. It was possible to have been contaminated by reactive rock associated with shearing and intrusion features.

Since the limitation of concrete alkali content to 3 kg/m^3 in 1994, there has not been any observation of ASR. Given that there has not been any change in the effort to isolate shear zones or intrusions from being quarried with the general mass, the improvement is likely to have been due to the limiting of concrete alkali content.

River sand

Hong Kong previously used sand dredged from the Pearl River for fines in concrete. Since the 1970s, its role has been taken over by fines crushed from rock. At present, river sand is used in some concrete as part of the whole fine aggregate to achieve higher workability. River sand is also used in cement mortar for rendering of concrete faces.

There have not been observations of alkali reaction of concrete comprising river sand and cement of normal alkali content. The present reduced use of river sand as fines would further lower the risk of reaction. Mortar for fixing tiles to walls is sometimes made from river sand. If ASR occurs, the stress might precipitate separation of the tiles from the wall.

Wu Shek Ku Quarry

Wu Shek Ku Quarry in Shenzhen supplied aggregates of volcanic rocks to Hong Kong in the early 1980s.

Shek Wu Hui Sewage Treatment Works was where ASR was first observed in Hong Kong. Gilbert (1995) reported a study of nine concrete cores recovered from the sedimentation tanks and aeration tanks. Eight thin sections and nine plates were produced on which petrographic examination was carried out. Microcrystalline and strained quartz was noted among the coarser grains of the volcanic rock aggregates.

Sewell and Campbell (2000) reported a study of ASR of a footbridge at Fanling. The affected concrete incorporating aggregate from Wu Shek Ku Quarry. Four concrete cores were taken from which 16 thin sections and 16 plates were produced for petrographic examination. The rock type of the aggregates was described as metatuff, strongly foliated, altered, mineralized with abundant finely recrystallized quartz, and strained quartz crystal.

There were no records of the quarry face geology or results of reactivity tests.

Anderson Road Quarry

AMBT conducted in PWCL on aggregates of volcanic rock (the volcanic aggregates) in this site gives a fourteenth day expansion of 0.309%. Anderson and Read (2002) reported values of 0.133% to 0.364% and mentioned petrographic examinations having been conducted on thin sections of the rock by Geomaterials Research Serivces Ltd.

Anderson & Read (2002) also reported AMBT and CPT tests aimed at showing the effectiveness of PFA in controlling ASR. They concluded that the volcanic aggregate from Anderson Road quarry could be use in concrete if the total alkali content of the concrete was limited to 3 kg/m^3, the concrete was not subject to severe exposure conditions, and 35% of the cement was replaced by PFA.

The quarry operator also engaged Taywood Engineering Ltd. to conduct a field test, in which 48 numbers of 400 mm square by 75 mm deep panels were cast of concrete of volcanic aggregates and mortar of a range of composition, to check their durability. The panels were sprayed with salt water at regular intervals daily to simulate an unfavourable environment. ASR was not observed on the panels. At an inspection in May 2004, the spray was found to be missing part of the panels due to sagging of the support benches. Regular running water on the panels could in the longer run leach out the alkali in the panels.

Cases of ASR

Table G1 lists confirmed cases of ASR in Hong Kong. It took about 9 to 16 years for the concrete to crack to an extent that drew suspicision of ASR

Table G1: Known Cases of ASR in Hong Kong.

Site	Year Constructed	Year ASR Reported	Approximate Time Lapsed
Shek Wu Hui Treatment Works	1980 - 1983	1991	10 years
Fanling foot bridge	1982	1998	16 years
North Point Government School	1986 - 1988	1999	12 years
Hill Road Flyover	Completed in 1982	1997	15 years
CLP Tseng Tsui Ash Lagoon	1988	1999	11 years

There have not been reports of ASR on mass concrete seawall blocks. Serious deterioration of reinforced concrete in marine environment occurred. Ingress of chloride and the spelling on concrete cover by the resulting corrosion of steel reinforcement was the main mechanism of such cases. SCCT (2000) prescribed measures to ensure durability of reinforced concrete in marine environment.

APPENDIX H

ALKALI AGGREGATE REACTION CONTROL FRAMEWORK FOR HONG KONG

H.1 INTRODUCTION

This note describes a framework for designing concrete against the risk of alkali silica reaction (ASR). It starts with classifying the structure to be built according to its tolerability to ASR. Based on the structure class and the quality of aggregates from available supply sources, measures to mitigate against ASR is assessed for the supply sources. Finally, the designer balances cost, risk of ASR and other utility considerations to decide what supply sources of aggregate the structure may accept.

The effectiveness of the concrete design framework relies on satisfactory control of the quality of aggregates that are supplied to concrete producers. This would in turn require testing of aggregates and control on the production process. This is described in the aggregate control framework in section 3 of the note.

The frameworks are formulated with in mind simplicity of use, consistence with local experience and international practice, and continuity with the present ASR control framework as far as possible.

H.2 CONCRETE MIX DESIGN FRAMEWORK

H.2.1 Structures

Structures for which the concrete mix is designed are to be assigned to one of the three classes in Table H1. The classification follows broadly the New Zealand system:

Table H1 - Classification of Structures According to the Potential Consequence of ASR

Class	Definition and Examples
1	Some deterioration from ASR is acceptable: e.g., temporary or short service life structures, easily replaceable elements.
2	Minor ASR and resulting cosmetic cracking is acceptable: e.g., most building and civil engineering structures, which design life is in the regime of tens to a hundred or so years.
3	No ASR damage is acceptable, even if only cosmetic - long service life or highly critical structures: e.g., nuclear installations, dams, tunnels, exceptionally important bridges or viaducts, structures retaining hazardous materials

H.2.2 Environment

All concrete mixes are to be designed for the moist aggressive environment.

H.2.3 Aggregates

Aggregates may be innocuous, potentially reactive or reactive. Their classification is described in Section H.3.1.

H.2.4 Design Requirements

Based on local and international experience, the following preventive measures are prescribed for ASR control.

Structure	Preventive Measures
Class 1	Innocuous or Potentially Reactive aggregate: - mitigation measures not needed
	Reactive aggregate: - use low alkali cement to limit alkali content to 3.0 kg/m^3, or - use cement of normal alkali content but PFA to replace not less than 25% of cement by mass.
Class 2	Innocuous aggregate: preventive measures not needed
	Potentially Reactive aggregate: - use low alkali cement to limit alkali content to 3.0 kg/m^3, or - use cement of normal alkali content but PFA to replace not less than 25% of cement by mass.
	Reactive aggregate: - Experience with preventive measures for use with Reactive aggregate in Hong Kong is very limited. Anderson & Read (2002) reported test results. Read & Anderson (2002) proposed guidelines. These and the wealth of information on international practice could be referred to for designing preventive measures. - Until more is known about the performance of the Reactive aggregate in Hong Kong, the effectiveness of mitigation measures in a particular design mix should be investigated, preferably by tests on concrete prisms. Class 2 structures constructed with Reactive aggregates should also be monitored for not less than 15 years; clients should be made well aware of this obligation.
Class 3	Innocuous aggregate: preventive mitigation measures not needed but advisable to keep to low alkali limit of say 3.0 kg/m^3.
	Potentially Reactive aggregate or Reactive aggregate: Particular concrete mix and monitoring requirements to be worked out for each structure.

In addition, SCCT (2000) prescribes measures for reinforced concrete in marine environment to ensure durability in general. See Appendix I for SCCT (2000) and the part of WBTC 5/94 on estimation of alkali content of concrete for general reference.

H.3 AGGREGATES SUPPLY FRAMEWORK

H.3.1 Tests

Petrographic examination to RILEM AAR-1 may be used to classify rock as ASR non-reactive or reactive. In case of doubt, carry out AMBT or CPT.

Accelerated Mortar Bar Test (AMBT) to RILEM AAR-2 can be used for ASR classification of rock as follows:

Expansion after 14 days < 0.10%: Non-reactive
Expansion after 14 days at 0.1% to 0.20%: Potentially Reactive
Expansion after 14 days > 0.20%: Reactive.

In case of difficulties in interpreting test results, e.g., for reasons of scattered results, carry out CPT.

Concrete Prism Test (CPT) to RILEM AAR-3 can be used for ASR classification of rock as follows:

Expansion after 1 year < 0.05%: Non-reactive
Expansion after 1 year at 0.05% to 0.10%: Potentially Reactive
Expansion after 1 year > 0.10%: Reactive.

Accelerated (60°C) Concrete Prism Test to RILEM AAR-4 may be used for ASR classification of rock as follows:

Expansion after 15 weeks < 0.03%: Non-reactive.

H.3.2 Innocuous Aggregates

Innocuous aggregates are those produced from rock tested to be non-reactive, in such a manner as to preclude contamination by potentially reactive materials along geological features in the rock mass. Assurance against contamination should include:

i) an assessment of the petrography of the rock in the quarry and its general geological background;

ii) a system of production, transportation and stockpiling of the aggregates to prevent contamination by other rock products; and

iii) sampling at the stockpile for confirmatory testing of the reactivity of aggregates.

The study of petrography and geology of the site should best be carried out at the exploration stage of a quarry. Where microcrystalline quartz or strained quartz is found along some geological features, the extent and trends of distribution of the particular features should be assessed. Quick testing by AMBT and confirmatory testing by CPT should be carried out on materials from these features for calibration and future reference.

A quality assurance scheme against contamination during production should include delineation of production zones in the quarry, to be adjusted regularly through confirmation of site geology by rock face mapping. Where variation in geology is high or where the geology as exposed differs much from that estimated before, the rock face mapping may have to be at greater frequency or be supplemented by exploratory drilling of the rock mass behind the quarry face. In serious cases, the petrography and geology of the quarry may have to be studied again.

A quality assurance scheme against contamination during transportation should include assignment of loading unloading facilities and transport vehicles specifically for the aggregates.

A quality scheme against contamination at the stockpile should include spatial isolation of the stockpiles from other rock products not subjected to the same quality assurance schemes.

Sampling of the stockpiles for testing should cover both the average materials and materials that appear different from the average. It could be subjected to petrographic examination, AMBT, CPT or their combinations.

The frequency of quarry face mapping and sampling at stockpiles should be designed on the basis of the site geology and the transportation and stockpiling arrangement.

The study of petrography and geology, mapping of quarry faces, the quality assurance schemes, and results of tests should be properly documented and maintained, for the examination of concrete producers for supply source assessment. In addition, thin sections for petrographic examination should be produced in sets of two; one is to be kept by the quarry operator and one to a central depository at the CEDD.

H.3.3 Potentially Reactive Aggregates

Potentially Reactive aggregates are those produced from rock on which AMBT or CPT expansion values are in the range of 0.1-0.2% and 0.05-0.10% respectively, as defined in Section H.3.1.

Granite aggregates, unless produced with tight quality control as described in Section H.3.2, should be taken as Potentially Reactive.

Sand dredged from the Pearl River Delta should be regard as Potentially Reactive until proved otherwise by tests or by studies on particular deposits.

H.3.4 Reactive Aggregates

Reactive aggregates are those produced from rock which AMBT or CPT expansion values are higher than 0.2% and 0.10% respectively, as defined in Section H.3.1.

Aggregates of unknown origin, e.g., many recycled aggregates, should be taken as Reactive.

APPENDIX I

CURRENT SPECIFICATIONS FOR DURABLE CONCRETE

Recommended Specification for

Reinforced Concrete in Marine Environment

Standing Committee on Concrete Technology

Standing Committee on Concrete Technology

Recommended Specification for Reinforced Concrete in Marine Environment

(Endorsed at SCCT Meeting No. 2/2000)

1. Constituent Materials

Cementitious Materials

1.1 All cement and supplementary cementitious materials shall comply with the following standards:

Ordinary and Rapid Hardening Portland Cement	:	BS 12
Portland-blast furnace cement	:	BS 146
Low heat Portland-blast furnace cement	:	BS 4246
Sulphate resisting Portland cement	:	BS 4027
Portland pulverised-fuel ash cement	:	BS 6588
Pulverised fuel ash (PFA) (except that the criterion for maximum water requirement shall not apply)	:	BS 3892
Blast furnace slag (BFS)	:	BS 6699

The Contractor shall nominate the source of any of the materials mentioned in above proposed to be used in each concrete mix.

1.2 Where there is a danger or high risk of chlorides ingress causing the reinforcement to corrode, the tricalcium aluminate (C_3A) component of the cement is very desirable to reduce the amount of chloride available to promote corrosion. Sulphate-resisting cements, which are low in C_3A content, may not be appropriate and their inclusion in concrete mixes for marine environment may need to be reviewed carefully before adopting.

Mineral Additive

1.3 Mineral additive shall comply with the following:

Condensed Silica Fume (CSF):CSA-A23.5- M86 (Canadian Standard)

Water

1.4 Water for mixing, curing and cleaning concrete shall be clean fresh water taken from the public supply.

Aggregate

1.5 Concrete aggregates shall be normal weight and shall comply with the requirements of BS882, "Aggregates from Natural Sources for Concrete". In addition, the aggregates shall meet the following:

(a) Particle Shape
Flakiness index shall not exceed 30%
Elongation index shall not exceed 35%.

(b) LA abrasion and sulphate soundness
The maximum Los Angeles Value (ASTM C131) shall be 30% loss and maximum sodium sulphate soundness (ASTM C88) weighted average loss shall be 6%.

1.6 Aggregate shall be obtained from a dedicated deposit having demonstrable ability to provide a consistent quality and grading of material for the duration of the Contract. Aggregates from marine sources shall not be permitted.

2. Chemical Admixture

2.1 A chemical admixture is defined as a constituent material of concrete other than cementitious materials, mineral additives, aggregates and water. The admixtures shall comply and be used in accordance with the supplier's recommendation. Chemical admixtures shall comply with the following:

Pigments for Portland cement and Portland cement products	:	BS 1014
Accelerating admixtures, retarding admixtures and water-reducing admixtures	:	BS 5075:Part 1
Superplasticising admixtures	:	BS 5075:Part 3

2.2 Where two or more admixtures are used in a concrete mix, the compatibility shall be verified in writing by the supplier with the following:
BS 5075 Concrete Admixtures

2.3 The use of chemical admixtures shall only be permitted subject to the Contractor carrying out prior testing on trial mixes in accordance with this specification.

2.4 The use of any chemical admixture containing chlorides is prohibited.

2.5 The Contractor shall submit relevant test data which demonstrates that the properties of concrete composed of the chemical admixture meets the requirements of this specification.

3. Maximum Water/Cementitious Content Ratio

3.1 The water/cementitious content ratio of the concrete mix shall not exceed 0.38.

4. Cementitious Content

4.1 Cementitious content is the combined mass of cement and the dry mass of Condensed Silica Fume (CSF) and the mass of either Pulverised Fuel Ash (PFA) or Blast Furnace Slag (BFS) per cubic metre of compacted concrete.

4.2 The cementitious content of the concrete mix shall be within the 380-450 Kg/m^3.

4.3 Either PFA or BFS shall be incorporated in the concrete as separate materials in accordance with the following requirements:

The proportion of PFA replacement shall be within the 25-40% range by mass of the cementitious content for normal applications,

If BFS is used instead of PFA, the proportion of BFS replacement shall be within the 60-75% range by mass of the cementitious content for normal applications and the 60-90% range by mass of the cementitious content for low heat applications.

4.4 The proportion of the dry mass of CSF replacement shall be within the 5-10% range by mass of the cementitious content.

5. Chemical Content

5.1 The acid soluble chloride ion content of all concrete shall be determined in accordance with BS 1881:Part 124:1988 “Methods for Analysis of Hardened Concrete”, and shall not exceed 0.02% of total weight of concrete.

5.2 The acid soluble sulphate content of all concrete expressed as SO_3 shall be determined in accordance with BS 1881:Part 124:1988 “Method for Analysis of Hardened Concrete” and shall not exceed 4% of total weight of concrete.

6. Alkali-Aggregate Reaction

6.1 The reactive alkali of concrete expressed as the equivalent sodium oxide per cubic metre of concrete shall not exceed 3.0kg.

7. Curing

7.1 After final set has taken place the concrete shall be cured for at least 7 days. All exposed surfaces shall be protected from the sun and wind immediately after the initial set has occurred and the concrete shall be kept moist by light water spray or other suitable means until curing methods are applied. Surfaces from which formwork has been removed before 7 days shall be cured for the remaining period.

Moist Curing

7.2 Concrete shall be covered by canvas, hessian or plastic sheets and kept continuously moist. Where plastic sheets are used, all edges of the sheeting shall be securely fastened so that no air circulation can occur. Alternatively, exposed surfaces can be cured by flooding or continuous sprinkling. Formwork left in position shall be kept continuously wet.

8. <u>Curing Compounds</u>

8.1 Curing compound shall be a proprietary type approved by the Engineer and shall have an efficiency index of not less than 90%. The use of curing compound shall be limited to the following types:

(a) Wax Emulsion

(b) Petroleum Hydrocarbon Resin

8.2 The minimum application rate shall be 0.2 litre/m^2 or the minimum stated on the certificate of compliance, whichever is greater.

9. <u>Cover to Reinforcement</u>

9.1 The cover to all reinforcement in all exposure zones shall be 75 mm. Detailing and fixing of reinforcement shall be such that this cover is achieved to a tolerance of -5 mm, +10 mm.

9.2 For flexural crack width design and control purpose, allowable crack width may be increased by a factor of 1.25.

10. <u>Minimum Characteristic Strength</u>

10.1 The minimum characteristic strength of the concrete mix shall be 45 MPa.

Specification Items for the Control of Alkali-Aggregate Reaction in Concrete

(Abstracted from WBTC 5/94)

Specification Items For
The Control of Alkali-Aggregate Reaction In Concrete

Measures to Control AAR in Concrete	1.01 Measures to control the occurrence of alkali-aggregate reaction (AAR) in concrete for all concrete elements shall be submitted to the Engineer for approval, unless in the opinion of the Engineer the concrete element concerned will not be subject to moisture ingress throughout its design life. In the absence of alternative proposals such control shall be achieved by limiting the reactive alkali content of the concrete as described in clauses 1.02 - 1.04.

Criteria: Limit on Reactive Alkali	1.02 The reactive alkali of concrete expressed as the equivalent sodium oxide per cubic metre of concrete shall not exceed 3.0 kg.

Equivalent Sodium Oxide (Na_2O) Content	1.03 (1) The equivalent sodium oxide (Na_2O) content of the concrete shall be calculated from the following expression: Equivalent Na_2O = A + B + C
	Where A is the sum of the acid-soluble alkalis (expressed as equivalent Na_2O) of cement, admixtures and water.
	B is equal to 1/6 the total alkalis of PFA (expressed as equivalent Na_2O).
	C is equal to 0.76 times the chloride ion (C1) of the aggregate.
	(2) The acid-soluble alkali content of the cement shall be determined in accordance with BS4550:Part2:1970 (excluding amendment AMD 7285, July 1992) and shall be taken as the average of the latest 25 daily determinations of equivalent sodium oxide plus twice the standard deviation of the results.
	(3) The acid-soluble alkali content of admixtures shall be determined in accordance with BS1881:Part 124:1988.
	(4) The acid-soluble alkali content of water shall be determined in accordance with APHA (17ed. 1989) Sections 3500-K and 3500-Na.

	(5)	The total alkali content of the pulverised-fuel ash shall be determined in accordance with BS4550:Part 2:1970 (excluding amendment AMD 7285, July 1992) and shall be taken as the average of 25 weekly determinations plus twice the standard deviation f the results.
	(6)	The equivalent sodium oxide content of the coarse and fine aggregates shall be calculated from the quantity of chloride ion present which shall be measured in accordance with BS812:Part 4:1976.

Submission	1.04 (1)	The following particulars of the proposed concrete mix shall be submitted to the Engineer:
		(a) HOKLAS endorsed test certificates not older than 6 months giving the results of tests required in Items 1.03(2) to (6).
		(b) calculation of the reactive alkali of the proposed mix.
	(2)	New HOKLAS endorsed test certificates giving the results of tests required in Items 1.03 (2) to (6) shall be submitted at quarterly intervals together with any necessary further calculations to demonstrate that the mix continues to comply with the limit on reactive alkali.

GEO PUBLICATIONS AND ORDERING INFORMATION
土力工程處刊物及訂購資料

A selected list of major GEO publications is given in the next page. An up-to-date full list of GEO publications can be found at the CEDD Website http://www.cedd.gov.hk on the Internet under "Publications". Abstracts for the documents can also be found at the same website. Technical Guidance Notes are published on the CEDD Website from time to time to provide updates to GEO publications prior to their next revision.

部份土力工程處的主要刊物目錄刊載於下頁。而詳盡及最新的土力工程處刊物目錄，則登載於土木工程拓展署的互聯網網頁 http://www.cedd.gov.hk 的"刊物"版面之內。刊物的摘要及更新刊物內容的工程技術指引，亦可在這個網址找到。

Copies of GEO publications (except maps and other publications which are free of charge) can be purchased either by:

writing to
Publications Sales Section,
Information Services Department,
Room 402, 4th Floor, Murray Building,
Garden Road, Central, Hong Kong.
Fax: (852) 2598 7482

or
- Calling the Publications Sales Section of Information Services Department (ISD) at (852) 2537 1910
- Visiting the online Government Bookstore at http://bookstore.esdlife.com
- Downloading the order form from the ISD website at http://www.isd.gov.hk and submit the order online or by fax to (852) 2523 7195
- Placing order with ISD by e-mail at puborder@isd.gov.hk

讀者可採用以下方法購買土力工程處刊物(地質圖及免費刊物除外):

書面訂購
香港中環花園道
美利大廈4樓402室
政府新聞處
刊物銷售組
傳真: (852) 2598 7482

或
- 致電政府新聞處刊物銷售小組訂購 (電話：(852) 2537 1910)
- 進入網上「政府書店」選購，網址爲 http://bookstore.esdlife.com
- 透過政府新聞處的網站 (http://www.isd.gov.hk) 於網上遞交訂購表格，或將表格傳真至刊物銷售小組 (傳真：(852) 2523 7195)
- 以電郵方式訂購 (電郵地址：puborder@isd.gov.hk)

1:100 000, 1:20 000 and 1:5 000 maps can be purchased from:

Map Publications Centre/HK,
Survey & Mapping Office, Lands Department,
23th Floor, North Point Government Offices,
333 Java Road, North Point, Hong Kong.
Tel: 2231 3187
Fax: (852) 2116 0774

讀者可於下列地點購買1:100 000，1:20 000及1:5 000地質圖：

香港北角渣華道333號
北角政府合署23樓
地政總署測繪處
電話: 2231 3187
傳真: (852) 2116 0774

Requests for copies of Geological Survey Sheet Reports, publications and maps which are free of charge should be sent to:

For Geological Survey Sheet Reports and maps which are free of charge:
Chief Geotechnical Engineer/Planning,
(Attn: Hong Kong Geological Survey Section)
Geotechnical Engineering Office,
Civil Engineering and Development Department,
Civil Engineering and Development Building,
101 Princess Margaret Road,
Homantin, Kowloon, Hong Kong.
Tel: (852) 2762 5380
Fax: (852) 2714 0247
E-mail: jsewell@cedd.gov.hk

For other publications which are free of charge:
Chief Geotechnical Engineer/Standards and Testing,
Geotechnical Engineering Office,
Civil Engineering and Development Department,
Civil Engineering and Development Building,
101 Princess Margaret Road,
Homantin, Kowloon, Hong Kong.
Tel: (852) 2762 5346
Fax: (852) 2714 0275
E-mail: wmcheung@cedd.gov.hk

如欲索取地質調查報告、其他免費刊物及地質圖，請致函：

地質調查報告及地質圖:
香港九龍何文田公主道101號
土木工程拓展署大樓
土木工程拓展署
土力工程處
規劃部總土力工程師
(請交:香港地質調查組)
電話: (852) 2762 5380
傳真: (852) 2714 0247
電子郵件: jsewell@cedd.gov.hk

其他免費刊物:
香港九龍何文田公主道101號
土木工程拓展署大樓
土木工程拓展署
土力工程處
標準及測試部總土力工程師
電話: (852) 2762 5346
傳真: (852) 2714 0275
電子郵件: wmcheung@cedd.gov.hk

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.

TECHNICAL GUIDANCE NOTES

TGN 1	Technical Guidance Documents