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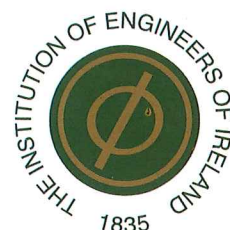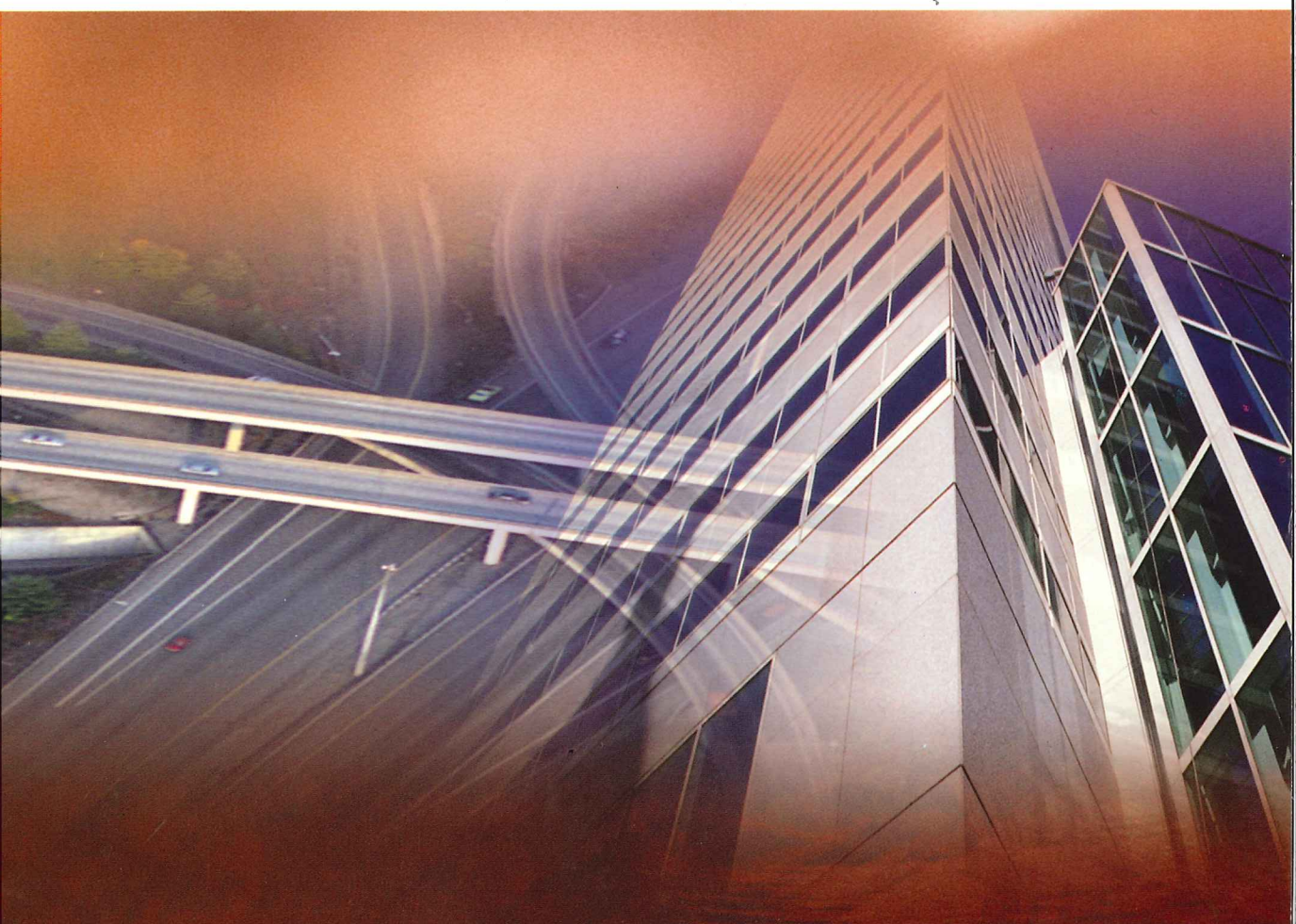
ALKALI-SILICA REACTION IN CONCRETE

NERAL RECOMMENDATIONS AND GUIDANCE

THE SPECIFICATION OF BUILDING

The Institution
of Engineers of Ireland

The Irish Concrete Society

Alkali-Silica Reaction in Concrete

General Recommendations and Guidance in the
Specification of Building and Civil Engineering Works

A Report prepared by a Joint Working Party

2003

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FOREWORD

The Institution of Engineers of Ireland and The Irish Concrete Society established a joint working party in November 1988 to examine alkali-aggregate reaction in concrete in the context of practice in the Republic of Ireland. The working party consisted of representatives of designers and specifiers, materials suppliers, design control authorities, researchers and educators. It adopted as its terms of reference:

"to consider the phenomenon of alkali-aggregate reaction in concrete with the purpose of making recommendations for its management in practice in the Republic of Ireland and in particular to produce guidance for the specification of future works".

A questionnaire was circulated widely throughout the country in 1989 to elicit whatever information might be available about the existence of concrete significantly affected by the reaction. No damage was reported.

The Report of the Joint Working Party was published in 1991 as an interim document that represented the best available knowledge at the time of the alkali-aggregate reaction in the context of conditions and practice in the Republic of Ireland. The report specifically referred only to alkali-silica reaction (ASR) as this was deemed to be the mechanism of relevance to Irish practitioners. The working party recommended that the document should be reviewed periodically as new materials and findings became available. The working party recommended that further study would be of value in the topics of testing and the role of chert in ASR behaviour.

Ten years later, in 2001, the text of European standard EN206-1 was approved and published by national standards authorities as a non-harmonised standard. The Standard requires actions to be taken to prevent deleterious ASR using procedures of established suitability, where aggregates contain varieties of silica susceptible to attack by alkalis and the concrete is exposed to humid conditions. Specifically, Clause 5.2.3.4 of I.S. EN206-1:2001 refers the practitioner in Ireland to the IEI/ICS report on ASR. It was felt timely therefore for the joint working party to be reconvened to review developments in concrete and recent research, both national and international. The joint working party met in 2001 and agreed to update the 1991 document. The membership of the working party was slightly revised to take account of the fact that not all members were available to participate in the updating process.

The joint working party invited submissions from national and international experts, sought information on any potential occurrences of ASR in the Republic of Ireland through notices in the technical press, and reviewed recent research. No cases of deleterious ASR were notified. The working party noted, in particular, research on secondary cementitious materials, the influence of chert, greywacke aggregates and developments in testing. The guidance has been updated in the light of these findings.

The working party is grateful in particular to Dr. Don W. Hobbs, Dr. Ciaran McNally and Dr. Peter Strogen for their input to the deliberations.

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SECTION 1

BACKGROUND

1.1   Introduction

Three factors determine the likelihood of potentially damaging alkali-silica reaction (ASR) in concrete. These are related to the presence of moisture, the presence of reactive silica and the alkali load. These three factors must be present simultaneously in sufficient quantity to pose a threat of reaction. Consequently, appropriate control of any one of these factors can be sufficient to adequately minimise the risk of potentially damaging alkali-silica reaction.

Concrete exposed to a dry, well-ventilated environment is at little or no risk of deleterious ASR and no precautions are necessary.

Concrete structures in industrial surroundings such as chemical process or waste treatments plants can be exposed to environments that cause an increase in their susceptibility to ASR. High temperatures, aggressive atmospheres, and chemical spillages can all add to the reaction and due cognizance should be taken of this fact.

1.2   Key factors

1.2.1   Moisture as a factor

Concrete, made from materials that are potentially reactive, will show signs of significant ASR only if the environmental conditions are conducive to its occurrence. A ready supply of moisture is the principal factor influencing the reaction. Where free moisture is not available, significant ASR cannot occur. The temperature cycle and range at which the concrete is maintained have an influence on the rate of reaction in ASR but it is difficult to generalise on the overall effect because different aggregates appear to behave differently. The initial rate of reaction seems to increase with higher temperatures but it has been reported that in some instances the maximum long-term expansion is achieved at relatively modest temperatures. The temperature cycle and range is not as important a factor as moisture. The particular environmental circumstances created by a particular project may also require consideration.

The main chemical reaction occurs between alkali in aqueous solution and reactive aggregates in the hardened concrete and a supply of free moisture is an essential ingredient in this process. The gel formed in the reaction is a hydrous silicate. The gel can expand by taking up moisture. The expansion can be sufficient to cause cracking of the concrete or to expand existing micro-cracks if a sufficient supply of moisture is available for some or all of the time. In practice, deleterious ASR only occurs where structures are subject over long periods to exposure to moisture in either the liquid or the vapour state.

In the liquid state moisture can come from such sources as driving rain, saturated ground (e.g. in the case of foundations), flowing water, heavy condensation, etc. Moisture can be supplied in the vapour state where the relative humidity is high for prolonged periods, e.g. in excess of 80%. It should also be noted that many water-resisting coatings do not inhibit vapour transmission.

Apart from obvious cases of high humidity, such as in swimming pool buildings, much exposed concrete in Ireland, even if sheltered from driving rain, is subject to high relative humidities for sustained periods. The relatively short term exposure that normally occurs during construction does not constitute severe exposure.

1.2.2 The silica factor

Most naturally occurring silica bearing aggregates react to a greater or lesser extent with the alkaline pore solution in concrete. Silica may occur in a variety of forms in aggregate, ranging from macrocrystalline quartz to amorphous opal. The degree of crystallinity is significant. Macrocrystalline quartz is inert under normal conditions whereas opal is the most reactive form of silica. Potentially reactive minerals can occur in both fine and coarse aggregates and it is always the aggregate combination as used in the concrete that must be considered, bearing in mind that the coarse and fine aggregates may come from different sources.

ASR-induced cracking of concrete requires an aggregate combination containing a critical amount of reactive silica together with a high alkali concentration and a moist environment.

Aggregates containing silica in the following forms may have the potential to react:
> Opaline silica, Cristobalite, Tridymite
> Cryptocrystalline and microcrystalline quartz as chert, flint and chalcedony
> Volcanic Glass

The original working party examined a database developed by the cement, aggregate, and concrete industries. This database contains geological and petrographic information on a significant number of aggregates and combinations of aggregate normally used in the manufacture of ready-mixed concrete throughout the country. Aggregate combinations other than those contained in the database may occur, for example when aggregates are transported outside the area they normally serve or when new sources are developed. In all 74 combinations of coarse and fine aggregate were examined and the occurrence of potentially reactive constituents in the normal combinations of coarse and fine aggregates was recorded.

Trace quantities (less than 1%) of opaline silica were found in only two sources of Irish limestones and rhyolitic gravels. Microcrystalline quartz, cryptocrystalline quartz and chalcedony are commonly found as a constituent of chert. Chert is composed largely of microcrystalline quartz but may contain small amounts of chalcedony. It is found in varying amounts (5 to 60%) in many Irish gravels, in Carboniferous and some older limestones (0-10%) and in some Lower Palaeozoic acid volcanic rocks (10-20%). Microcrystalline quartz is also found dispersed in the matrix of most graywackes and in siltstones, though its amount is difficult to estimate accurately. Flint, composed of cryptocrystalline to microcrystalline quartz, is found in Cretaceous chalk in Antrim, and in traces (1-3%) in some gravels along the northeastern coast and to a lesser extent on the eastern coasts. Volcanic glass is only found in small quantities in Tertiary basalts.

Thus aggregates used in concrete in Ireland may contain significant amounts of microcrystalline quartz, mainly as chert. The majority of these cherts are of Carboniferous age and have undergone deformation and low grade metamorphism involving heating to temperatures in excess of 200°C. The result has been to stabilise their crystalline structure. Cherts from the Cretaceous era, which are younger than, and have a different geological history to the Carboniferous cherts, are known to have a less stable crystalline structure and have been used in concrete in countries where deleterious expansion due to ASR has been identified. Flints from the Cretaceous era have been found in Northern Ireland and on the east coast of Ireland.

Greywacke aggregates occur in Ireland. Greywackes have been shown to be potentially reactive in certain areas of the world. No cases of deleterious reaction have been identified in concretes containing greywacke in the Republic of Ireland. Laboratory evaluation of Irish greywackes has indicated that reactivity potential varies significantly. These considerations have been taken into account in developing the recommendations presented in Section 2.5.1.

1.2.3 The alkali factor

Alkali-silica reaction occurs in concrete when hydroxyl ions, present in the pore water solution of concrete, react with certain forms of silica in the aggregate to form a gel which can absorb water, swell, and exert a pressure within the concrete which can cause cracking. The hydroxyl ion concentration of the pore solution in concrete is controlled principally by alkalis in the cement. This alkalinity can be further increased if the concentration of the alkali metal ions sodium (Na^+) and potassium (K^+) in the pore solution is increased due to the nature and composition of the binder; chloride-bearing aggregates; the chemical composition of the mixing water; and any admixture included. External sources of alkalis, in particular road de-icing salts, may also be significant depending on the application rate and, where appropriate, the drainage details.

Where an aggregate-cement combination is suspected of potential ASR one approach is to limit the alkali content of concrete. The alkali content of concrete, in kilograms per cubic metre (kg/m³), is defined as the total amount of alkali contributed from the cement, secondary cementitious materials, aggregates, mixing water and admixtures. The alternative approach is to use a 'low alkali' cement. Cements with alkali contents less than or equal to 0.60% are generally regarded as being low alkali cements and as being suitable for use even with highly reactive aggregates.

Cement
In the context of ASR, the alkali content of the cement is dependent on the quantity of sodium oxide (Na_2O) and potassium oxide (K_2O). The alkali content is normally represented by the acid soluble equivalent sodium oxide content ($Na_2O_{equiv.}$), expressed by the following formula:

$$Na_2O_{equiv.} = Mass\ \%\ Na_2O + 0.658 \times Mass\ \%\ K_2O$$

Alkali levels can be reported by the manufacturer in a number of ways. A common method is to report the certified average alkali content, which is defined as the average of the last 25 determinations of alkali content carried out on consecutive daily samples.

Variability may be taken into account by reference to the standard deviation of the results.

The alkali content of Portland cements throughout the world generally falls in the range 0.30 to 1.50%. The alkali content of Portland cement (CEM I) complying with EN197 produced in the Republic of Ireland is currently (2003) in the range 0.6 to 0.7%. Sulfate resisting Portland cement produced to BS 4027 generally has a lower alkali level than normal Portland cement (CEM I). Sulfate resisting Portland cement manufactured in the Republic of Ireland currently (2003) has an alkali content in the range 0.45 to 0.55%.

Secondary Cementitious Materials
Incorporation of ground granulated blast furnace slag (ggbs) and pulverised fuel ash can have a beneficial effect in reducing expansions caused by alkali-silica reaction. Although these materials generally have much higher total alkali contents than Portland cement the alkali is usually combined in the material in such a way that not all of it is available for reaction in the pore water solution of the concrete.

Advice varies internationally on the amount of reactive alkali contributed by secondary cementitious materials and how such alkalis should be taken into account in calculating the total alkali content of concrete. A recommendation on this issue is included in Clause 2.5.

Aggregates
Most Irish aggregates are unlikely to contribute any reactive alkali to concrete. If aggregates contain salt the alkali contributed by the sodium chloride needs to be considered. This is only likely to arise where beach, estuarine or sea-dredged aggregates, not pre-washed with fresh water, are used to produce concrete. A recommendation on this issue is included in Clause 2.5.

Mixing Water

Mixing water from potable sources in Ireland is unlikely to contribute any reactive alkali to concrete.

Admixtures

Some admixtures contain small quantities of alkalis. The contribution to concrete alkali level can be calculated by reference to the admixtures alkali content and dosage rate. A recommendation on this issue is included in Clause 2.5.

1.3 Other issues

1.3.1 De-icing salt and other salts

The significance of de-icing salt and other salts should never be overlooked. Water, apart from being the medium through which the reactive components are brought together, can also be a vehicle for introducing additional alkalis into the concrete. These alkalis can be from sources such as de-icing salt in the case of bridge decks, or sea spray in the case of marine structures, and they can migrate into the concrete thus increasing the alkali concentration.

Alkalis from external sources such as ground water, de-icing salt, and industrial processes cannot be ignored in a consideration of ASR. Buried concrete can be subjected to a concentration of alkalis present in the mix constituents due to localised capillary action. Alkalis, if present in the ground water, can further increase any alkali concentration that may be brought about by this effect. In some industrial processes, saturation of the concrete with alkalis may occur. Sometimes such an effect is accompanied by high temperatures, which may exacerbate the ASR problem. The application of de-icing salt to concrete roads and bridges may increase the alkali load on a concrete. The potential for problems due to de-icing salt is normally managed by adequate waterproofing and/or drainage systems.

1.3.2 Air-entrainment

The gel resulting from ASR may be found in air voids in concrete which contains a reactive aggregate, but which does not show a deleterious expansion. The gel appears to migrate through undamaged concrete to fill air voids and this suggests that air entrainment may reduce the risk of cracking due to ASR. Tests have shown that expansion is reduced in concrete with air voids. An effect of the gel filling the air voids may be to reduce the resistance of the concrete to freeze-thaw cycles.

1.4 Petrographic examination and test methods

The petrographic description and categorisation of aggregate deposits is difficult. This is, firstly, because aggregates vary in their geological age, and secondly because of the heterogeneity of both bedrock and especially sand and gravel deposits. The second effect can be minimised by adequate sampling procedures. The difficulty is emphasised by the fact that concretes with apparently similar aggregates have suffered deleterious expansion in some parts of the world and not in others. Part of this difficulty is related to the huge difference in geological age of aggregate sources of the same petrographical classification, ranging from a few years (Iceland) to literally billions of years. Aggregate sources in the Republic of Ireland range in age from 300 million to 1.5 billion years.

It is generally accepted that the previous history of use of an aggregate in concrete is a prime indicator as to whether it has the potential for deleterious ASR or not. When new aggregate sources are being exploited or when there is reason to reassess a well-known source, a petrographic analysis of aggregate should be undertaken. It is strongly recommended that the petrographer undertaking the analysis have a good working knowledge of concrete as a material and also of the phenomenon of ASR. It should be borne in mind that the sample of aggregate used for any assessment must be representative of the current aggregate production.

Quick chemical tests, accelerated mortar bar expansion tests and long term concrete prism expansion test methods have been developed that may give an indication of the behaviour of an aggregate combination in service. The chemical tests include ASTM C289. Mortar bar expansion tests involve monitoring the expansion of mortar bars stored in a moist environment maintained at 38°C (ASTM C227) or in alkaline solutions at 80°C (RILEM Method AAR-2 and B.S.I. BS DD249). Concrete prisms expansion tests involve storage in a moist environment maintained at 38°C (RILEM Method AAR-3 and B.S.I. BS 812-123).

The accelerated mortar bar test environment is very harsh. The test may therefore serve best as a rapid screening test. Expansions below 0.10% might clear an aggregate for unrestricted use. Values above 0.10% could indicate a need for further testing.

Expansion tests on concrete prisms are more long term but in time may develop to the stage of being definitive. The RILEM Method AAR-3 utilises a prescribed recipe leading to an alkali load of about 6 kg Na_2O_{eq} /m³. The British Standards Institution method is based on a prescribed cement content by volume and an alkali content of 1.0%, which leads to an alkali load in the concrete of about 7 kg Na_2O_{eq} /m³. Prisms are monitored for a year. Research on ASR involving reactive greywacke aggregates has highlighted their potential to slowly expand. A period of storage of 2 years is therefore recommended for testing greywackes. A variation on the standard concrete prism method has been issued by the British Cement Association for the testing of greywackes at various alkali loads. A further variation, in which concrete prisms are stored at 60°C has been proposed by RILEM as Draft Method AAR-4 to reduce the period of test.

None of these tests are definitive in the Republic of Ireland, taking into account the limited knowledge of their applicability in Irish conditions. The alkali load in the expansion tests is higher than that experienced in practice and is higher in the British Standard than the RILEM method. The test results, in conjunction with petrographic examination, may be helpful in deciding if the aggregates are classifiable as unlikely to be deleteriously alkali-reactive, in which case no precautions against ASR are necessary. However it should be noted that no aggregate should be rejected solely on the basis of testing in accordance with these methods.

SECTION 2

RECOMMENDATIONS

The recommendations in this Section should be read where appropriate with the more detailed discussion of the issues in Section 1. The following recommendations assume that highway structures will not be exposed to de-icing salts at dosage levels and rates significantly higher than heretofore. A flowchart summarising the recommendations is presented in Figure 1.

2.1   Risk assessment

The advice given in these recommendations is aimed at ensuring that the risk of damage from ASR in concrete is given due attention. Consideration should be given to the risk of damage occurring, taking into account the likelihood and consequence of such damage. When this risk is considered by the designer to be acceptable, specific precautions against ASR need not be taken.

Whenever a clause is written into a specification that restricts the producer in the choice of materials, or requires an additional guarantee, the result may be an additional cost. There will be many cases where, although there may be no guarantee, it will not be considered appropriate to introduce into the specification additional clauses to minimize the risk of damage from ASR, either because the possibility of ASR is judged sufficiently remote, or because the additional expense is not warranted. The decision on whether precautions are necessary or not should take into consideration, amongst other factors, the importance of the structure and how closely the expected construction materials and methods come to satisfying the recommendations which follow. The guidance provided in this document is based on national and international research findings together with experience of the satisfactory performance of aggregates in Irish concrete practice to date.

Notwithstanding the above, a decision not to take specific precautions in respect of the risk of damage from ASR in concrete in any structure should never be taken if the safety of users of the building / structure, or other persons, will be put at increased risk.

2.2   Situations requiring specialist advice

There is insufficient experience of high performance concrete in Ireland to date to be able to give general guidance here. Specifically, specialist advice should be sought where cement contents exceed 500 kg/m^3.

2.3   Moisture

Experimental results and other evidence gathered in the U.K. and elsewhere in the last 30 years have shown that, where the relative humidity within the concrete can be maintained, for the full service life, at less than 80% after curing, cracking from ASR will not occur, and no special precautions will be needed. Such conditions can be expected within dry, well-ventilated parts of buildings and other structures. In other cases, however, such conditions of permanently low relative humidity may not normally apply: for instance, in the case of foundations, cladding or other externally exposed members, reservoirs or other water retaining structures, buried concrete, highway structures, multi-storey car parks, swimming pool buildings, or concrete in other locations where condensation is likely to occur. In some such cases it may be possible to ensure that the relative humidity is artificially controlled at less than 80%, for example by tanking basements. However, as noted in Section 1, such measures must ensure vapour transmission is prevented and many water-resisting coatings do not do this.
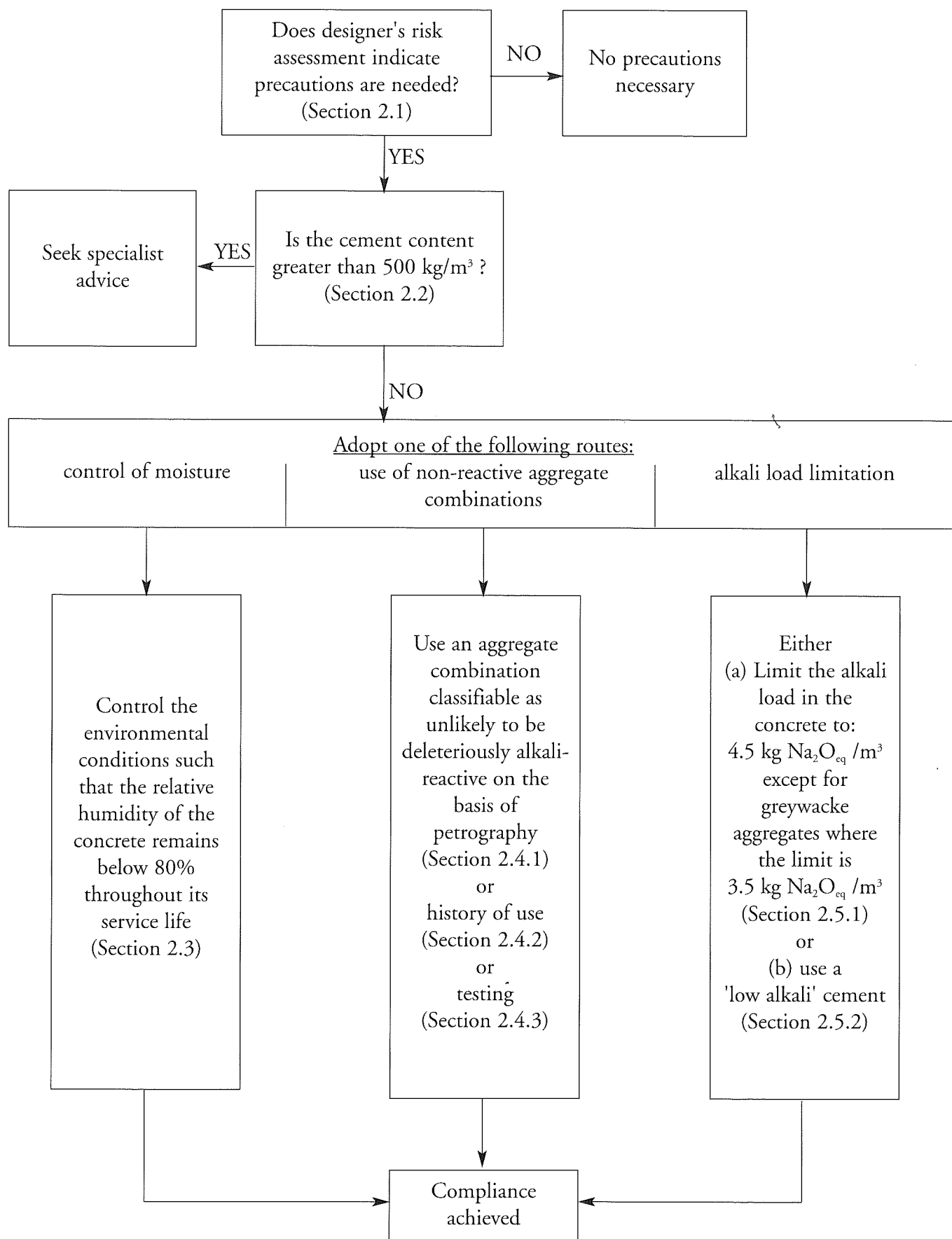
```
┌─────────────────────┐                    ┌──────────────────┐
│ Does designer's risk │        NO          │  No precautions  │
│ assessment indicate  │ ─────────────────> │    necessary     │
│ precautions are      │                    │                  │
│ needed?              │                    │                  │
│ (Section 2.1)        │                    │                  │
└─────────────────────┘                    └──────────────────┘
            │ YES
            ▼
┌──────────────┐   YES   ┌─────────────────────┐
│ Seek         │ <────── │ Is the cement content │
│ specialist   │         │ greater than 500 kg/m³ ?│
│ advice       │         │ (Section 2.2)        │
└──────────────┘         └─────────────────────┘
                                   │ NO
                                   ▼
```

Adopt one of the following routes:

| control of moisture | use of non-reactive aggregate combinations | alkali load limitation |

Control the environmental conditions such that the relative humidity of the concrete remains below 80% throughout its service life (Section 2.3)

Use an aggregate combination classifiable as unlikely to be deleteriously alkali-reactive on the basis of petrography (Section 2.4.1) or history of use (Section 2.4.2) or testing (Section 2.4.3)

Either
(a) Limit the alkali load in the concrete to:
4.5 kg Na_2O_{eq} /m³ except for greywacke aggregates where the limit is
3.5 kg Na_2O_{eq} /m³ (Section 2.5.1) or
(b) use a 'low alkali' cement (Section 2.5.2)

Compliance achieved

Fig. 1 Flowchart summarising recommendations

2.4   Aggregate classification

Aggregates may be deemed unlikely to be deleteriously alkali-reactive on the basis of petrographic examination alone or on the basis of its petrographic examination combined with the history of use of that aggregate combination and/or with the results of laboratory testing.

2.4.1   Petrographic examination

Records of the petrography of aggregates proposed for use are significant in the context of assessing the risk of ASR. Aggregates should be petrographically examined by an experienced petrographer to identify the presence, if any, of certain minerals or rocks that may be potentially reactive. Guidance in this regard may be found, for example, in British Standard BS7943:1999 and RILEM Method AAR-1.

If the content of potentially reactive minerals or rock in the aggregate combination is at or below the limits presented in Table 1 the aggregate combination may be classified as unlikely to be deleteriously alkali-reactive on the basis of petrographic examination alone and no further precautions against ASR are necessary. If the content of potentially reactive minerals or rock in the aggregate combination is above the limits in Table 1, the aggregates may be acceptable, at the specifier's discretion, following consideration of petrographic examination combined with history of use of that aggregate combination and/or with the results of laboratory testing – see Sub-sections 2.4.2 and 2.4.3.

Potentially reactive mineral or rock	Content Limit
Opaline silica Cristobalite Tridymite	Zero
Microcrystalline and cryptocrystalline quartz Chalcedony, flint and chert[1] Volcanic Glass	5%
Note [1] Aggregates used in concrete in the Republic of Ireland have significant amounts of chert containing chalcedony and microcrystalline quartz. The majority of these cherts are of Carboniferous age and have undergone deformations and low grade metamorphism. This has stabilised their crystal structure and they have a low potential reactivity compared with geologically younger materials. Cherts from the Cretaceous era have been found in Northern Ireland and on the east coast of Ireland. These younger materials have a different geological history to the Carboniferous cherts, have a less crystalline structure and might be significant if used in circumstances potentially susceptible to ASR.	

Table 1: Potentially reactive mineral or rock: content limit

2.4.2   History of use

In the Republic of Ireland there is a history of use of many aggregate combinations and to date there has been no reported case of deleterious ASR. The history of use of combinations of aggregates that have performed well in concrete in the past can assist in evaluating the acceptability of such aggregate combinations in proposed works. Where the specifier can be satisfied that the proposed combinations of aggregates have a history of satisfactory use in concrete of a similar mix and in similar environmental

conditions and over a period of at least 20 years, the specifier may decide that no further precautions are necessary. In this context an aggregate means a specific lithology from a specific locality. In the case of new aggregate sources, petrographic examination may reveal strong relationships with an existing source whose record is impeccable. Such new sources may be treated as equally non-suspect.

Clearly history of use does not apply in situations where experience of the concrete mix proposed in the particular circumstances of a project is very limited or non-existent and in that regard it is emphasised that there is insufficient experience of concrete in Ireland to date with cement contents in excess of 500 kg/m³.

2.4.3 Testing

Test methods, such as those referred to in Section 1.4, may give an indication of the behaviour of an aggregate or aggregate combination. International development of test methods is particularly directed at expansion testing. These include tests on mortar bars and concrete prisms.

It is generally accepted that accelerated mortar bar expansion tests are not definitive. However if aggregates or aggregate combinations exhibit little or no expansion in mortar bar tests they may, if considered in conjunction with petrographic examination or records, be classifiable as unlikely to be deleteriously alkali-reactive. No further precautions against ASR are necessary in such instances. Long-term expansion tests on concrete prisms generally require a test period of twelve months but this may need to be doubled in the case of greywacke aggregates. They are regarded internationally as being more definitive than mortar bar expansion tests but have not been proven to be so reliably definitive in the Republic of Ireland. However, they also may be helpful in making a judgement that aggregates are classifiable as unlikely to be deleteriously alkali-reactive, in which case no precautions against ASR are necessary.

2.5   Alkalis

Another acceptable approach to controlling within acceptable limits the risk of occurrence of deleterious ASR is to either limit the alkali content of the concrete to the values indicated in Sub-section 2.5.1. or alternatively, to use a 'low alkali' cement as described in Sub-section 2.5.2.

2.5.1 Alkali load limitation

Consider the alkali contribution of relevant constituents in accordance with the methodology set out in Table 2 and limit the alkali load in the concrete to the maximum values indicated in Table 3. The maximum alkali load permitted is dependent on the presence, if any, of greywacke aggregate.

The alkali load in the concrete can be summed from the following potential contributors as appropriate: cement, secondary cementitious materials, aggregates, admixtures and water. The methodology to be applied (Table 2) is illustrated through sample calculations for three mixes, presented in the Appendix.

2.5.2 'Low alkali' cement

Use a 'low alkali' cement. Such a cement is defined as one with a certified average alkali content of less than or equal to 0.60%, including allowance for variability of 1.64 standard deviations.

Contributor	Contribution	Determination
Cement	Certified average alkali content plus an allowance for variability of 1.64 standard deviations, factored by cement content.	Cement content x (Average Na_2O_{eq} + 1.64 standard deviations) Na_2O_{eq} = Na_2O + 0.658 K_2O
Ground granulated blastfumace slag	If ggbs content is less than 40%: One hundred per cent of acid soluble alkali content plus an allowance for variability of 1.64 standard deviations, factored by ggbs content.	ggbs content x (Average Na_2O_{eq} + 1.64 standard deviations) if ggbs content < 40%
	If ggbs content is equal to or greater than 40%: Fifty per cent of acid soluble alkali content plus an allowance for variability of 1.64 standard deviations, factored by ggbs content.	ggbs content x 0.5 (Average Na_2O_{eq} + 1.64 standard deviations) if ggbs content ≥ 40%
Pulverised fuel ash	If pfa content is less than 21%: One hundred per cent of acid soluble alkali content plus an allowance for variability of 1.64 standard deviations, factored by pfa content.	pfa content x (Average Na_2O_{eq} + 1.64 standard deviations) if pfa content < 21%
	If pfa content is equal to or greater than 21%: Twenty per cent of acid soluble alkali content plus an allowance for variability of 1.64 standard deviations, factored by pfa content.	pfa content x 0.2 (Average Na_2O_{eq} + 1.64 standard deviations) if pfa content ≥ 21%
Aggregates	Chloride ion content, expressed as a percentage by mass, factored by 0.76. May be ignored if the chloride ion content is less than 0.02 %.	0.76 x (Cl^- content) unless Cl^- < 0.02 %
Admixture	Alkali content of admixture, if any, factored to take account of dosage rate.	(Na_2O_{eq}) x dosage rate factor
Water	Chloride ion content, expressed as a percentage by mass, factored by 0.76. May be ignored if the chloride ion content is less than 0.02 %.	0.76 x (Cl^- content) unless Cl^- < 0.02 %

Table 2: Summation of alkali load value

Aggregate	Maximum alkali load
Aggregate other than greywacke	$4.5\ Na_2O_{eq}\ kg/m^3$
Greywacke aggregate	$3.5\ Na_2O_{eq}\ kg/m^3$

Table 3: Alkali load limitation values

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DEFINITIONS

Acid soluble equivalent sodium oxide content. A material property of cement determined through the sum of the acid soluble sodium oxide content and the acid soluble potassium oxide content factored by 0.658.

Alkali-aggregate reaction. Term embracing the phenomena of alkali-carbonate reaction, alkali-silica reaction, alkali-silicate reaction.

Alkali load. See Alkali content of concrete.

Alkali content of constituent materials. The alkali content determined from the acid soluble equivalent sodium oxide content (q.v.). Usually expressed as a percentage (%).

Alkali content of concrete. The total amount of alkali contributed (if any) from the cement, secondary cementitious materials, aggregates, mixing water and admixtures. Usually expressed in kilograms per cubic metre (kg/m^3).

ASR. Alkali-silica reaction.

Certified average alkali content. The average of the last 25 determinations of alkali content carried out on consecutive daily samples.

Low alkali cement. Generally regarded as cements with a certified average alkali content of less than or equal to 0.60%.

Na_2O_{equiv} Acid soluble equivalent sodium oxide content (q.v.).

APPENDIX

Calculation of Alkali Content of Concrete - Worked Examples

Example 1   CEM I mix

Example 2   CEM I / pfa mix

Example 3   CEM I / ggbs mix

CALCULATION OF ALKALI CONTENT OF CONCRETE
Example 1: Total alkali content of a Normal Portland Cement mix (CEM I) with an admixture

Item	Constituent	Quantity	Properties	Alkali Contribution
1	Cement	350 kg/m³	Certified average alkali content: 0.65% Na_2O_{eq}. Standard deviation: 0.03%	350 [0.65 + 1.64 (0.03)] / 100 = 2.45 kg/m³
2	Coarse aggregate D20	750 kg/m³	Chloride ion content: 0.03%	750 (0.76) (0.03) / 100 = 0.17 kg/m³
3	Coarse aggregate D10	380 kg/m³	Chloride ion content: 0.03%	380 (0.76) (0.03) / 100 = 0.09 kg/m³
4	Fine aggregate	750 kg/m³	Chloride ion content: 0.01%	Nil
5	Admixture	1.5 l/m³	Average alkali content: 0.3% Na_2O_{eq}.	1.5 (0.3) / 100 = 0.01 kg/m³
6	Water	180 l/m³	Chloride ion content: 0.004%	Nil
				Total 2.7 kg/m³

Example 2: Total alkali content of a mix incorporating pulverised fuel ash

Item	Constituent	Quantity	Properties	Alkali Contribution
1	Cement	290 kg/m³	Certified average alkali content: 0.65% Na_2O_{eq}. Standard deviation: 0.03%	290 [0.65 + 1.64 (0.03)] / 100 = 2.03 kg/m³
2	Pulverised fuel ash	120 kg/m³ (circa 30%)	Certified average alkali content: 1.50% Na_2O_{eq}. Standard deviation: 0.03%	120 (0.2) [1.50 + 1.64 (0.03)] / 100 = 0.37 kg/m³
3	Coarse aggregate D20	735 kg/m³	Chloride ion content: 0.02%	735 (0.76) (0.02) / 100 = 0.11 kg/m³
4	Coarse aggregate D10	350 kg/m³	Chloride ion content: 0.02%	350 (0.76) (0.02) / 100 = 0.05 kg/m³
5	Fine aggregate	780 kg/m³	Chloride ion content: 0.01%	Nil
6	Water	145 l/m³	Chloride ion content: 0.004%	Nil
			Total	2.6 kg/m³

Example 3: Total alkali content of a mix incorporating ground granulated blastfurnace slag

Item	Constituent	Quantity	Properties	Alkali Contribution
1	Cement	210 kg/m³	Certified average alkali content: 0.65% Na_2O_{eq}. Standard deviation: 0.03%	210 [0.65 + 1.64 (0.03)] / 100 = 1.47 kg/m³
2	Ground granulated blastfurnace slag	140 kg/m³ (40%)	Certified average alkali content: 0.60% Na_2O_{eq}. Standard deviation: 0.03%	140 (0.5) [0.60 + 1.64 (0.03)] / 100 = 0.45 kg/m³
3	Coarse aggregate D20	740 kg/m³	Chloride ion content: 0.02%	740 (0.76) (0.02) / 100 = 0.11 kg/m³
4	Coarse aggregate D10	375 kg/m³	Chloride ion content: 0.02%	375 (0.76) (0.02) / 100 = 0.06 kg/m³
5	Fine aggregate	685 kg/m³	Chloride ion content: 0.01%	Nil
6	Water	155 l/m³	Chloride ion content: 0.004%	Nil
				Total 2.1 kg/m3