MANAGING ASR IN THE REPUBLIC OF IRELAND.

John W. de Courcy
University College Dublin.

Nicholas M. Ryan
Environmental Research Unit Dublin.

The background to the current Irish approach to the management of ASR, as contained in the joint report of the Institution of Engineers of Ireland and the Irish Concrete Society, is presented, and areas still requiring research are identified.

INTRODUCTION

In 1988, the Institution of Engineers of Ireland and the Irish Concrete Society, recognizing the significance of the alkali-aggregate reaction in Irish concrete practice, established a joint working party to review the subject on their behalf and to offer relevant recommendations and guidance for new works in the Republic of Ireland. The working party 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"

It was decided that the appraisal of affected structures would not be considered in detail.

In October 1990 a draft for a proposed report was circulated for public comment, and at that time also the draft was tabled at a seminar to which representatives of all relevant interests were invited.

Following consideration of the comments received, the working party submitted its report entitled "Alkali-silica reaction -general recommendations and guidance on the specification of building and civil engineering works" to the two commissioning bodies in 1991, and it was accepted by them later that year. It is this Report that the present paper introduces. It is to be understood that, as in other countries, it is an interim document dealing solely with normally proportioned concrete being made and used in the Republic of Ireland.

THE IRISH CONCRETE INDUSTRY

The following statistics relate to the Concrete Industry in the Republic of Ireland.

1) Portland cement concrete has been used since the period 1850-1860.

2) Portland cement was first made in the period 1880-1890.

3) Reinforced concrete has been in use since the period 1895-1905.

4) Portland cement was not made in the period 1920-1938.

5) Portland cement has been made in three plants under one general management since 1938, and the two plants at present in use supply about 85% of all cement used.

6) Approximately 5 million cubic metres of concrete, in a broad sense, were made in the year 1991. This includes in-situ and precast structural concrete, roads and other pavement, blocks and bricks, other products as for example kerbs, fence posts, lamp standards and pipes, and Portland-cement-based mortars and renderings.

THE ALKALI-AGGREGATE REACTION

Formal studies of AAR which began in the Republic during the period 1975-1985 were described by Bannon in a paper to the Institution of Engineers of Ireland in 1987 (1). Whilst he reported that "no cases of damage to concrete due to alkali-aggregate reactivity have been identified in Ireland", he suggested nevertheless that a specific approach to this subject should be developed for the Republic, to be "based on our knowledge of and experience with Irish materials and practice". The formal discussion of his paper supported that suggestion.

It was an immediate decision of the Working Party early in 1989 to seek information from the Concrete Industry about possible examples of significant AAR in existing structures. To this end, a questionnaire was issued to all Local Authority Engineers, Consulting Engineers, Architects, Contractors, and others involved in the design, construction, and maintenance of our stock of concrete structures. It was recognised, in issuing the questionnaire, that very few of those to whom it was addressed would have had any practical experience of AAR. Accordingly, some short guidance notes were issued, indicating the categories of structure most likely to be attacked and offering some pointers for the identification of affected concrete. One instance was reported in which hardened concrete exhibiting the reaction in an industrial environment had been damaged by spillage of hot alkali solutions. It is thought that this damage originated by thermal shock rather than by the AAR. Other than this no damage was reported in the representative response received from the Industry.

Whilst it is accepted that there are three types of the AAR phenomenon, the report deals primarily with alkali-silica reaction (ASR). It considers that alkali-silicate reaction may be regarded in the Republic of Ireland at the present time, as a rare sub-set of ASR and treated accordingly. Alkali-carbonate reaction is not considered, as the aggregates that can lead to it have not been identified as being used in structural concrete in this country.

The Alkali Factor

It is considered that the alkalis in Irish concrete come primarily from the cement. The weather regime here is such that little use is made of de-icing salt in the maintenance of frost-free road surfaces. The significance of industrial salts and marine conditions and the possible influence of alkaline ground water on buried concrete are of course noticed.

Historically, ordinary Portland cements made in the Republic of Ireland have had medium to high alkali contents, ranging from 0.70% to 1.00%, and this figure is at present being stabilised at about 0.85%. The alkali content of a cement is established in the Report as a certified average alkali content which is "the average of the last 25 determinations of alkali content carried out on consecutive daily samples" plus an allowance for variability of 1.64 standard deviations from that average. Thus a cement having an average content, based on samples, of 0.85% with a standard deviation of 0.04% would be deemed to have an alkali content of 0.85 + 1.64 x 0.04 = 0.92%

The quantities of blastfurnace slag and pulverised fuel ash used here to date have been negligible. It is possible however that pfa may come into use in the future. Its contribution to the alkali content of cement, or of concrete, is to be based on a 17% acid soluble sodium oxide equivalent content plus a variability allowance of 1.64 standard deviations on measured samples. The contribution made by the use of admixtures is also to be taken into consideration, as also is any contribution made by alkalis in the aggregate.

Some sulphate-resisting Portland cement is made in the Republic of Ireland and this at present has an alkali content of approximately 0.55%.

The Silica Factor

Reactive silica, if present, comes wholly from the aggregates. Aggregates in the Republic are taken almost exclusively from two categories of source. Either they are dug from naturally occurring glacial and other fluvial deposits and if necessary crushed, or they are extracted from quarries and crushed as required. Marine-dredged aggregates have not so far been used, and the use of shore-based sands and gravels is firmly discouraged. The introduction of micro-silica (silica fume) is not recommended.

The bedrock geology of Ireland is dominated by carboniferous limestones. There is some basalt occurring in the North, some gritstone in the North-east, and some sandstone in the South. Granite occurs in the mountains of Leinster, in the Mourne Mountains and in the counties of Galway, Mayo, and Donegal. The younger cretaceous limestone, which includes cretaceous chert, occurs only in isolated areas mainly on the north-east coast.

The total area of Ireland, including the Republic and Northern Ireland, is 83000 square kilometres. For the general assessment of aggregates the island has been divided into seven reference areas as shown on Figure 1

It will be seen that area 7 contains County Donegal and includes the whole territory of Northern Ireland. It must be made clear that the Report now being introduced does not apply to works carried out in that territory. It must however be included as a potential source for aggregates for the Republic, particularly as the western part of area 7 contains County Donegal which is not rich in local sources; and it and the northern parts of areas 2 and 6 use some cross-border materials.

A data base consisting of 108 sources of aggregates spread throughout the seven reference areas in the Republic has been made by the cement, aggregate, and concrete industries, and this was used in the preparation of the Report. It is recognised that the coarse and fine aggregates used in a particular concrete may come from different sources, and that it is the combination of aggregates that must be considered in assessing the vulnerability of a concrete to ASR. It is however also recognised that, unless some special circumstances apply, the aggregates will be drawn from sources as close as convenient to the construction site. On this understanding, 74 likely combinations of coarse and fine aggregates have been assessed.

An examination of those combinations indicates that the occurrence in them of potentially reactive constituents is as shown in Table 1.

TABLE 1 Potentially reactive minerals in Ireland

Mineral Group	Occurrence	Reference Area (Fig. 1)
Opaline Silica Cristobalite Tridymite	Trace quantities (less than 1%) found only in two sources of Irish limestones and rhyolitic gravels	1,7
Microcrystalline and Crypto-crystalline Quartz and Chalcedony	Commonly found as a constituent of chert. Chert is found in varying amounts (5% - 60%) in limestone and sandstone gravels, greywacke and mudstones	1, 2, 3, 4, 5, 6, 7
Volcanic Glass	Found in volcanic deposits such as basalt and in gravels and sands containing volcanic rocks. Generally the quantity of volcanic glass was less than 5%, but two occurrences greater than 5% were noted.	7
Highly strained Quartz	Not yet identified in aggregates in Ireland	No occurrence

It can be seen that such significant substances as opaline silica, cristobalite, tridymite, volcanic glass, and highly strained quartz are extremely rare in Irish aggregates. On the other hand, chert is very common in the limestone bedrock and in gravels and sands derived from it. This chert is however almost wholly associated with the older carboniferous limestone rather than with the younger cretaceous limestone. As such it has a more stable crystalline structure than cretaceous chert, a material that includes what is sometimes described as flint. Flint pebbles are found on seashores all along the east coast of Ireland, and are believed to come from underwater deposits in the Irish sea and Saint George's Channel.

It is generally and properly accepted that the history of previous use of an aggregate in concrete is a prime indicator as to whether or not it has the potential for deleterious ASR. There has been little change in the nature of the sources used for aggregates in the Republic during the last half century, and it is quite clear that the sometimes considerable content of carboniferous chert in the aggregate coupled with the relatively high level of alkali in the cement used during that period has not led to any significant appearance of the reaction. This freedom from attack has been an important factor in the thinking of the working party, although sight has not been lost of either the need to assess new quarried sources closely or to overlook the growing tendency for large contents of cement.

The nature of carboniferous chert in the context of ASR is seen as a topic in which research is desirable and particularly so in this country. It is an area in which even now work is in progress, and in which it will continue. In this regard and in the overall assessment of aggregate, the co-operation of petrographers is seen as essential, but these must be scientists who, in addition to their geological skills, have a deep understanding both of concrete as a material and of its use in the Industry.

Other Factors

(a) The Report advises that significant ASR can be considered to be almost totally confined to structures or parts of structures, in the open air or where moisture has free access. Moisture in a vapour state is considered to constitute a risk where the relative humidity is high, that is to say, in excess of 80% over prolonged periods, and it is pointed out that this level frequently applies in Ireland. Freedom from moisture is a condition that needs very critical assessment in this country, and one unlikely to be invoked unless the circumstances are very clear. In this context, however, it is accepted that short term exposure during construction does not of itself constitute a hazard.

(b) The report published by the Institution of Structural Engineers in 1988 on the structural effects of alkali-silica reaction (2) deals with the influence of reinforcement on the integrity of structures affected by ASR. The value of triaxial reinforcement is clear. The Report for this country acknowledges this to be so, but notes that the effect is incidental and not normally a primary matter in design.

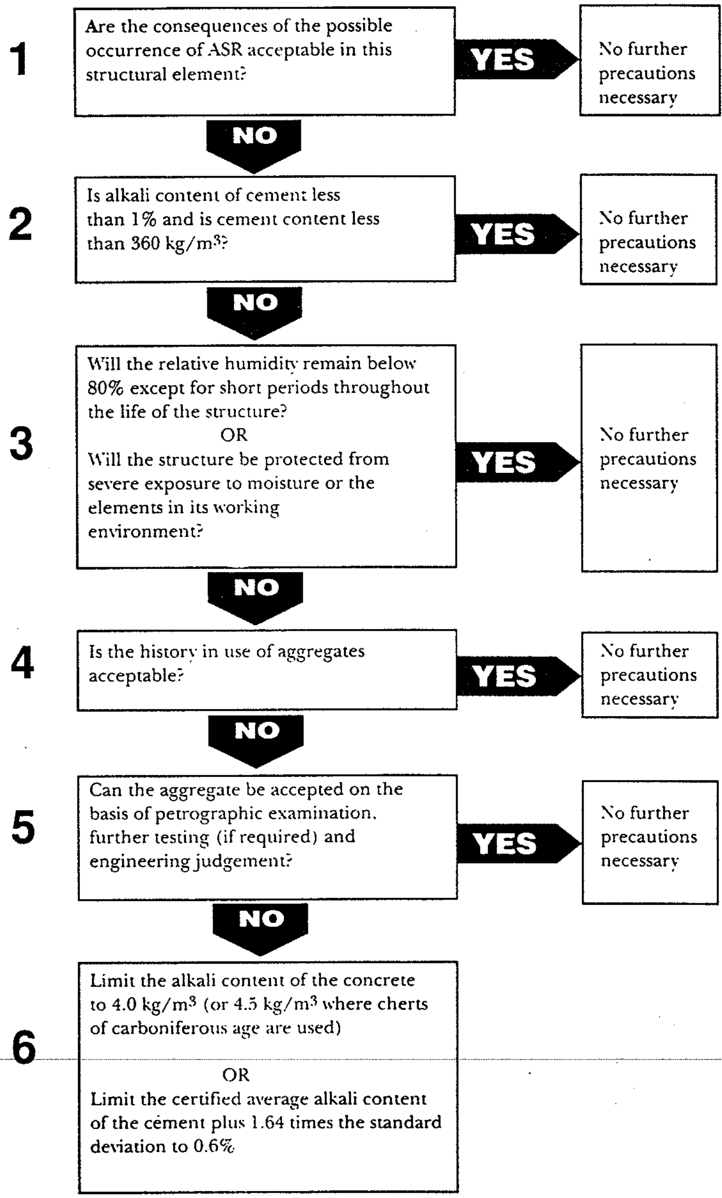
(c) In accordance with international experience, the Report recognises the ameliorative effect of air voids in concrete. While it notes the value of air entrainment, it accepts that a decrease in freeze-thaw resistance can follow reduction of the volume of voids which are partially filled with gel. The relatively mild climate regime in Ireland may however make the decreased resistance less significant than in many other countries.

(d) The special environments of concrete structures in aggressive industrial surroundings are seen as requiring extra attention.

RECOMMENDATIONS

Following a brief summary of the principles embodied in the guide lines of the United States of America, Germany, the United Kingdom, Japan, and Denmark, the Report offers recommendations for minimizing the risk of damage due to alkali-silica reaction in the Republic. It includes a flow chart, shown here as Table 2, which envisages six possible sets of circumstances. These are now discussed.

TABLE 2 - Flow chart showing procedure for assessment of possible risk and measures to minimize the risk of damage due to ASR in Irish practice.



1 Are the consequences of the possible occurrence of ASR acceptable in this structural element? YES: No further precautions necessary

2 Is alkali content of cement less than 1% and is cement content less than 360 kg/m^3? YES: No further precautions necessary

3 Will the relative humidity remain below 80% except for short periods throughout the life of the structure?
OR
Will the structure be protected from severe exposure to moisture or the elements in its working environment? YES: No further precautions necessary

4 Is the history in use of aggregates acceptable? YES: No further precautions necessary

5 Can the aggregate be accepted on the basis of petrographic examination, further testing (if required) and engineering judgement? YES: No further precautions necessary

6 Limit the alkali content of the concrete to 4.0 kg/m^3 (or 4.5 kg/m^3 where cherts of carboniferous age are used)
OR
Limit the certified average alkali content of the cement plus 1.64 times the standard deviation to 0.6%

(1) Consideration of the likelihood of damage and of the risks and economic implications may suggest that no specific precaution needs to be taken against ASR.

(2) Very many uses of concrete are based on a nominal cement content of 360 kg or less per cubic metre of finished concrete. It will be stated later in this paper that the alkali content of concrete should normally be limited to 4.0 kg per cubic metre. If then the alkali content of the cement, which includes an allowance for variability, does not exceed 1% (and this is an extremely high figure) the alkali content of 360kg concrete will not exceed 3.6kg per cubic metre. Under such circumstances further attention to ASR is not required in that concrete. This is seen as a significant recommendation of convenience, frequently appropriate but not to be invoked if de-icing or industrial salts are to be applied to the hardened concrete or if secondary cementituous materials are to be added at the mixer.

(3) This topic is as discussed earlier.

(4) This topic is as discussed earlier. The history of aggregates in use plays a significant part in this assessment in the relatively small land area of the Republic. Its authority is however seen as less certain with higher strength concrete. Experience in the Republic with the long-term behaviour of concrete having specified 28 day strengths of 45N/mm^2 or more is limited.

(5) If there is insufficient evidence of satisfactory history of use, if new aggregate sources or combinations are being used, or if an aggregate is in any way suspect, and if the nature of the aggregate is to be the guiding parameter, an approved petrographic assessment must be made. The American Standard ASTM C295 - 85 (3) may be followed using the guidance limits given on Table 3.

<u>TABLE 3</u> **<u>Petrographic Examination - Guidance Limits</u>**

Minerals or rocks	Percentage of combined aggregate	
	Unlikely to be reactive	Further evaluation required
Opaline Silica Crystobalite Tridymite	–	Any amount
Microcrystalline and Cryptocrystalline Quartz, Chalcedony (1)	5% or less	Greater than 5%
Volcanic Glass	5% or less	Greater than 5%
Highly strained Quartz	30% or less	Greater than 30%

(1) This category includes chert and flint

The prominence of carboniferous chert in Irish aggregates has been mentioned earlier. It is possible that the guidance limit given in Table 3 for micro-crystalline and cryptocrystaline quartz and chalcedony is conservative. There is an implication that deleterious expansion will occur if this figure, which is taken from the international literature, is exceeded, but it is anticipated that further research may lead to its revision upwards.

If the guidance limits are exceeded and further evaluation is required, the Report suggests that such tests as ASTM C289 (4) and ASTM C227 (5) may be helpful in assisting engineering judgement to accept or reject an aggregate. These tests however have not been fully substantiated for Irish aggregates. It is not recommended that they be used alone, and the development of other standard methods would appear to be an important area for research.

(6) In considering the control of the alkali content of concrete, it is necessary to know the alkali content of the cement and how it is determined. The Report proposes that manufacturers certify the average and standard deviation of 25 samples. The alkali content is then based on those figures, with the acceptable number of standard deviations being taken as 1.64. Examples of the alkali content of concrete would then be as in Table 4.

Table 4 Variability Allowance in Alkali Content.

Certified Average Alkali Content of Cement	Standard deviation	Alkali Content		Cement dosage	Alkali Content of Concrete	
		Without SD Allow-ance	With SD allowance		Without SD Allow-ance	With SD Allow-ance
%	%	%		kg/m³	kg/m³	kg/m³
0.60	0.04	0.60	0.66	400	2.40	2.64
				500	3.00	3.30
0.85	0.04	0.85	0.92	400	3.40	3.68
				500	4.25	4.60

Using this approach the maximum limit of the alkali content of the concrete is recommended to be set at 4.0kg per cubic metre or, if chert from carboniferous limestone is the critical material present, at 4.5 kg. per cubic metre. These figures rely on the history of the aggregates as it is known in the Republic of Ireland and on a careful consideration of on-going research elsewhere. It should perhaps be stressed that there is no evidence in this country of the use of highly reactive opaline aggregates or of cretaceous flint, both of which materials have been included in the tests upon which control limits have been based in other countries.

There will be instances where the alkali content of the concrete exceeds the stated limits of 4.0 or 4.5 kg per cubic metre, or where the importation of an aggregate or the opening of a new aggregate source in Ireland introduces an uncertainty. For such instances, an alternative approach is suggested that limits the alkali content of the cement (which includes an allowance for variability) to 0.60%. In presenting these figures and those in Table 4 it will be appreciated that alkali introduced by other additions to the cement or concrete would also have to be taken into account.

SPECIFICATION

The Report concludes with a set of model clauses suggested for use in project specifications.

REFERENCES

1. Bannon, C.A., 1987 - Trans, IEI, Vol. CXI, p-187-244.

2. Institution of Structural Engineers, 1988. "Structural effects of alkali-silica reaction, interim technical guidance on appraisal of existing structures," Institution of Structural Engineers, London.

3. ASTM, C295-95. Standard practice for petrographic examination of aggregates for concrete.

4. ASTM C289-87, Standard test method for potential reactivity of aggregates (chemical method).

5. ASTM, C227-87, Standard test method for potential alkali-reactivity of cement-aggregate combinations (mortar -bar method).

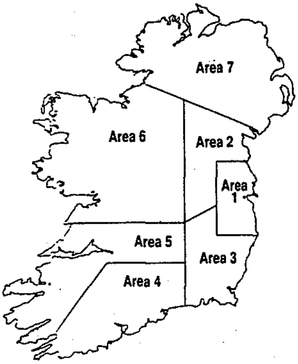


Figure 1 - Reference areas used for aggregate classification in Ireland.