PROCEDURES FOR ASSESSING THE POTENTIAL ALKALI-REACTIVITY OF AGGREGATE SOURCES

G P Hammersley
Laing Technology Group Ltd, Page Street, Mill Hill
London NW7 2ER

This paper highlights the importance of a geological site inspection when assessing the potential alkali reactivity of aggregates. Procedures are described for carrying out this inspection and the associated sampling as part of a structured investigation of an aggregate source. The procedures described have been developed for the assessment of existing quarries on a routine commercial basis, but the underlying strategy and principals are relevant to exploration for new sources.

INTRODUCTION

Many laboratory test methods have been developed for assessing the potential alkali-reactivity of aggregates. These include the recognition of potentially reactive constituents by petrographic examination, chemical methods to determine the response of the aggregate to alkaline solutions and various forms of expansion tests. There has been much research and debate over the years on the reliability of the respective methods with different countries adopting different routes for assessing alkali-reactivity. In all cases the validity of the test result is ultimately dependant on the test sample being representative. Typically the samples submitted for testing consist of processed aggregates taken from stockpiles. Even with good sampling practice such samples can never represent more than the batch from which they were taken. This is particularly relevant in the case of alkali-aggregate reaction (AAR) where potentially reactive material may occur only locally within the quarry such as highly siliceous beds within limestone or as potentially reactive siliceous vein material.

If the desired objective is to evaluate the potential alkali-reactivity of an aggregate source then a thorough geological appraisal of the source is essential. This is recognised by the Department of Transport in its Specification for Highway Works (1) which requires the geological inspection of a quarry if the aggregate is to be classified as non-alkali reactive.

This paper describes procedures for carrying out a geological appraisal of a quarry to assess the potential alkali-reactivity of the product. These procedures have been developed for the assessment of existing quarries on a routine commercial basis, primarily in relation to alkali-silica reactivity, but are equally relevant to the detection of alkali-reactive carbonate rocks. The underlying strategy and principals are also applicable to the exploration for new sources, as described by the Geological Society (2). Although this paper is restricted to assessing potential alkali-reactivity the geological investigation can provide information on the presence of many potentially deleterious substances as described by Hammersley (3). These substances include:- *

(i)	Porous and frost susceptible particles
(ii)	Weak or soft particles, or coatings
(iii)	Rock types susceptible to shrinkage and swelling
(iv)	Coal, lignite and other forms of organic matter
(v)	Salts
(vi)	Iron pyrites and other metallic contaminants
(vii)	Mica
(viii)	Shells

*Some of these may only be deleterious in certain situations or above a certain concentration.

PLANNING AND PERSONNEL

Planning

The investigation should follow a logical plan and while this may vary in detail depending on the objectives and local circumstances, it should generally include the principal stages shown on Figure 1. Because of the variable nature of geological materials it may be necessary to revise the original schedule of work at various stages in the investigation and it is important that this flexibility is allowed for at the outset, with sufficient opportunities to review progress.

Personnel

The investigation should be undertaken by a suitably qualified geologist with particular experience in the properties and production of aggregates.

DESK STUDY

The desk study is an essential part of the investigation and should be substantially completed prior to commencement of the site work, as the information revealed may have an important bearing on the planning of the site inspection, sampling and subsequent laboratory work. The desk study should attempt to establish the following:-

(i)	The location of the quarry.
(ii)	Details on the operator.
(iii)	The geological nature of the rock or deposit with as much relevant information as possible, particularly on composition, weathering, alteration and mineralisation.
(iv)	The aggregate products available and their history of use particularly where there is documented information on mix designs.
(v)	Existing test data for the aggregate
(vi)	Existing quality control and quality assurance procedures where these exist.

The quality and quantity of the above information will obviously vary enormously from one quarry to another and for different countries. Potential sources of information include, but are not limited to:-

- (i) Topographic maps
- (ii) Geological maps
- (iii) Geotechnical, geomorphological, tectonic or other special maps
- (iv) Memoirs, notes or special publications associated with the maps
- (v) Regional geological guides
- (vi) Technical papers or books
- (vii) Mineral assessment or land use reports
- (viii) Original survey data for the quarry or subsequent extensions
- (ix) Borehole records from the original development or subsequent extensions
- (x) Records, test reports or quality manuals at the quarry.

SITE INSPECTION

Briefing And Preliminary Inspection

On arrival at the quarry an initial briefing should take place with relevant staff to obtain any further information, define the objectives of the site inspection and agree the detailed plan for the inspection. This should include compliance with all local safety procedures.

A preliminary tour of the quarry and processing plant should be made preferably with a member of staff to determine the overall layout and geological setting, inspect any local features known to the quarry staff and establish areas of current working with any safety restrictions. In the light of this preliminary inspection the opportunity should be taken to review the plan for the main site work.

Detailed Inspection

Objectives And Scope. The form of the site inspection will inevitably vary depending on factors such as the nature of the quarried material (sand, gravel or rock), its structure, composition and variability, the size and mode of operation of the quarry and the specific objectives of the overall investigation.

The site inspection should establish:-

- (i) The overall geological nature of the rock or deposit.
- (ii) The compositional variability of the material
- (iii) Structural features which may affect the composition of the aggregate as working proceeds.
- (iv) The presence and extent of weathering, alteration, mineralisation, veining and special local features.

Inspection Sequence. With most quarries being operated as a series of benches it is usually most practical for the inspection to be undertaken in sequence through the benches, generally starting at the bottom. The actual sequence of inspection will also be governed by the geological structure, for example in a quarry working a sedimentary rock the inspection should proceed logically through the geological sequence of strata. If the geological sequence can be established early on this can minimise unnecessary sampling and speed up the inspection.

The inspection should not be limited to active areas of the quarry as disused faces can yield vital information on the geological sequence and special features such as veining or minor intrusions, which may reappear in the active faces in the future. Neighbouring outcrops and even other local quarries may need to be inspected in some circumstances.

Standardised descriptive schemes. The adoption of a standardised scheme for the description of the rock or deposit and the use of standard forms for recording information are most important.

Rock names should be assigned using appropriate geological classification schemes. Where several alternative schemes exist, for example with limestones, reference should be made to the classification used. A geological classification should also be used to describe the constituents of sands and gravels, as far as is possible in the field. With both rock and unconsolidated deposits (sands and gravels) it is recommended that the above compositional classification is incorporated within the formal framework provided by an engineering geological description of the rock or soil mass. Engineering geological descriptive schemes for rocks and soils have been described by working parties of the Geological Society 4, 5, 6) and a development of these is given in BS5930:1981 (7) which is recommended for use.

Occurrence of potentially reactive materials. In undertaking the inspection, attention should be given to the likely modes of occurrence of the potentially reactive materials, which sometimes may be as minor or highly localised features within the quarry. Potentially alkali-reactive material can be broadly classified into one of three modes of occurrence shown on Table 1.

Occurrences of type 3 pose particular problems of detection, illustrating the need for detailed examination of the quarry faces. Such occurrences could very easily be missed by occasional sampling of production aggregate. Undetected opal veins in the rock processed for coarse aggregate resulted in damaging alkali-silica reaction in the spillway of the Kamburu Dam in Kenya (8).

Recording of data. The site inspection is facilitated if the results are recorded on standard forms. An example of a suitable form is shown on Figure 2 for a granite quarry. Separate forms may be used for an entire bench level or just one face of a bench, depending on the complexity of the situation. The form allows for an overall description of the rock or deposit, followed by a detailed description of specific features of interest giving location, sample and photograph reference numbers.

Location reference numbers should be shown on a layout plan of the quarry. If relevant the principal geological units can also be shown on this plan together with any features of particular interest such as minor intrusions or areas affected by potentially deleterious veining.

TABLE 1 - Modes of occurrence of potentially alkali-reactive materials.

Mode of Occurrence	Examples *
(1) A constituent distributed throughout the entire rock or or deposit within the quarry.	(i) Quarries operating in a single rock type containing potentially reactive silica such as - some glassy volcanic rocks - some gneisses - some sandstones (ii) A sand or gravel deposit with a potentially reactive constituent, such as chert
(2) A constituent within only a part of the rock or deposit in the quarry.	(i) A particular horizon within a sedimentary rock, such as a siliceous bed within a limestone (ii) A particular band within a metamorphic sequence (iii) Part of a composite igneous intrusion.
(3) A constituent of a localised or minor feature within the rock or deposit - often a secondary feature resulting from mineralisation or intrusion.	(i) Certain types of siliceous veining (ii) Chert nodules within limestones. (iii) Certain types of silica infilling vugs and cavities

* Note: The examples given are not an exhaustive list.

Method of working and processing. The method of working the quarry can have a very significant effect on the variability of the aggregate product and this should be taken into account during the site inspection. The method of processing can also influence the composition of the aggregate product, for example potentially reactive silica could occur within highly weathered shear zones or minor intrusions, which due to the lower strength of the material might be lost as fines during crushing and screening. The inspection should therefore include the processing plant, stockpiles and waste piles.

SAMPLING

Sample Types

An essential element of the work is the collection of samples for laboratory analysis and testing. An outline sampling programme should have been formulated prior to commencement of the detailed inspection, but this will invariably need refinement during the course of the inspection. The following types of samples can be taken:-

(i) Samples From Quarry Faces:-

(a) Samples of the rock or deposit selected to represent the observed range in lithology, rock type or composition as appropriate.

(b) Samples selected from specific features of interest such as veins, inclusions, lenses or weathered horizons.

(ii) Samples Of The Aggregate Product
- (a) Representative samples of the stockpiled aggregates collected in accordance with standard practice such as BS812:Part 102:1989 (9)
- (b) Selected particles from stockpiles or waste piles.

Samples of type (i) selected from the quarry faces are essential. Samples of type (ii) can only represent a relatively short period of aggregate production, but they can be useful, for example in demonstrating the effect of the extraction and processing operation on the composition of the final product. They are likely to be used most frequently for sand and gravel deposits where the method of extraction and processing often tends to average the composition of what may on a small scale be a very variable material.

The size of the samples should reflect the nature of the material and the requirements of the intended laboratory work. Where petrographic examination and perhaps associated chemical or instrumental analysis are to be undertaken hand specimens of rock from the quarry face are suitable. The size of the hand specimen should be governed by the nature of the rock, but a minimum of about 2 Kg is recommended. For similar studies on unprocessed sand and gravel or processed aggregates bulk samples will be required and the guidance of BS812:Part 102:1989 (9) should be followed as a minimum, but larger samples may be required if the site inspection suggests that constituents of interest are present as only trace proportions. Guidance on sampling is also given in ASTM D75-82 (10).

For special laboratory tests larger samples may be required and the specific test methods should be consulted.

Quarry Reference Samples

It has been found helpful to duplicate samples collected from the quarry face, especially rock samples, so that a reference set can be left with the quarry. These may subsequently be useful for future quality control, aiding staff to spot potentially deleterious material where selective quarrying is being operated.

LABORATORY WORK

Only a brief mention is made here on laboratory methods as there is a wealth of published work in this area with numerous national standards.

The laboratory work should commence with a careful visual examination of the samples aided as appropriate with a stereoscopic microscope and simple mineralogical recognition tests, such as scratch hardness or effervescence in acid. On the basis of this examination decisions can be taken on the subsequent laboratory work, which has been separated on Figure 1 into three categories:-

- (i) Petrographic examination
- (ii) Chemical and instrumental analysis
- (iii) Special methods

Categories (i) and (ii) are concerned with the recognition of potentially reactive constituents, while category (iii) covers expansion tests and various forms of chemical tests to measure the degree of reactivity of the constituents.

For most situations the laboratory work will be principally within categories (i) and (ii). Guidance on petrographic examination is provided by the Geological Society (2), a draft for consideration as BS812:Part 104 (11) and ASTM C295-85 (12). Depending on the requirements of national standards and local specifications various special tests may also be required.

CONCLUSIONS

When it is necessary to determine whether a source of aggregate is potentially alkali-reactive, reliance solely upon the laboratory testing of samples of production aggregate is generally unsatisfactory due to the inherently variable nature of natural geological materials. The assessment of the source should include a geological inspection of the quarry and the procedures outlined above form a basis for this inspection. The procedures described are equally relevant to the detection of many other deleterious constituents which may sometimes occur in natural aggregates.

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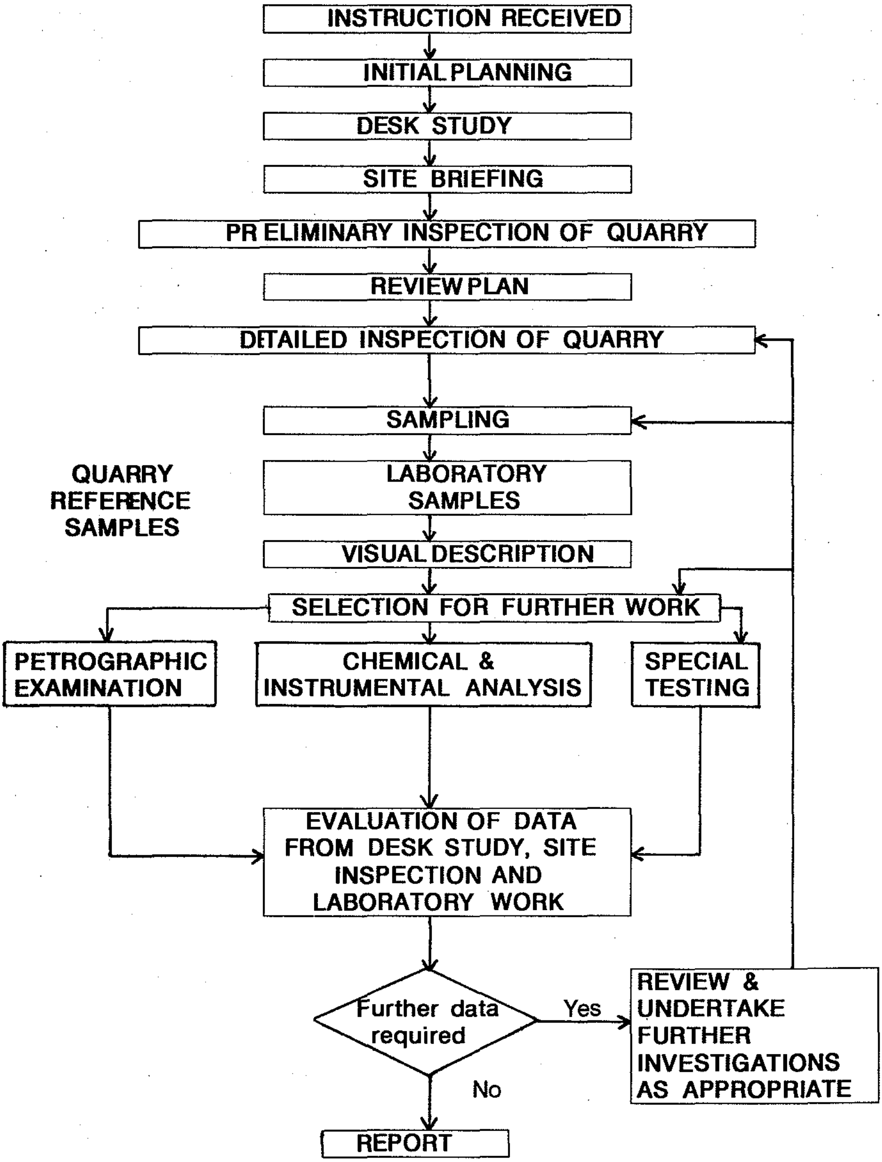

Figure 1. Flow Chart Showing The Principal Stages in the Evaluation of the Potential Alkali–Reactivity of An Aggregate Source

INSPECTION OF QUARRY FACES

Quarry	NORTH HILL QUARRY
Part of Quarry	New Quarry
Level	340
Face	West
Face Height	20m approx
Active Working	At north end

GENERAL DESCRIPTION	Photo Ref.
Pink course grained faintly weathered GRANITE with medium to large blocky jointing. Granite cut by DOLERITE dykes and SILICEOUS veins.	
General view of face	1

Location Ref.	DETAILED DESCRIPTION	Sample Ref.	Photo Ref.
1	Typical granite	1 (H)	2
2	Granite cut by dyke composed of dark greenish grey medium grained moderately weathered DOLERITE. Width 1.6 to 2.0m, Dip 82° to 274° mag.	2 (H)	3,4
3	Granite cut by 3 No. light grey fine grained SILICEOUS veins. Width 10 to 35mm, Dip 60-75° to 260° mag.	3,4,5(H)	5
4	Typical granite	6(H)	
5	Granite cut by light grey fine grained siliceous vein. Width 45mm. Dip 70° to 290° mag.	7(H)	6

Inspected By	A Geologist	Date	1.4.1992	Sheet 1 of 3

Figure 2. Example of the Record of Inspection for a quarry face.