ALKALI SILICA REACTION (ASR) POTENTIAL OF SAND AND GRAVELS FROM NW-HIMALAYAN RIVERS AND THEIR PERFORMANCE AS CONCRETE AGGREGATE AT THREE DAMS IN PAKISTAN

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ABSTRACT: *Concrete aggregates derived from the river bed materials of many of the streams originating from the NW-Himalayan region and draining into Pakistan are found reactive in terms of Alkali-Silica Reaction (ASR). This paper describes the long term ASR related performance of concrete at three dams i.e., Warsak, Tarbela and Mangla where material from such streams has been used as concrete aggregates. On Warsak an aggressive and at Tarbela a mild ASR has been detected while at Mangla dam ASR free concrete is reported. The anomaly of occurrence and non-occurrence of ASR in concrete manufactured using aggregate derived from the same provenance has been described.*

Key words: Aggregates, Concrete, Alkali – Silica Reaction, Dams

INTRODUCTION

Himalayan region forms a border between the Indian sub-continent and the rest of the Asia. The region comprises rugged mountain chains, V-shaped very deep valleys and many of gigantic streams draining the plains of Indian sub-continent. The prominent streams include Indus, Ganges and Brahamputra. Geologically the area is complex and comprises a wide variety of igneous, metamorphic and sedimentary rocks. The streams originating from the region and draining Nepal, Pakistan, Bhutan and India have a huge potential for hydropower generation.

NW-Himalayan rivers in Pakistan on which some hydropower projects were completed in past and many more future hydropower development schemes have been proposed; have their catchments belonging to NW Himalayas. Many factors particularly the young and immature geology and landform of Himalayas aggravated by the action of glaciers and tropical climate (hot summer followed by heavy monsoon) are responsible for immense degradation of land. These factors have resulted in rivers of the region carrying a lot of load belonging to the rock types exposed in their respective catchment areas.

Owing to less efforts required for manufacturing the aggregates, these streams are always attractive sources of concrete aggregates for investors at mega projects, and have also been used at many hydropower projects in the past. It is anticipated that they will remain potential sources for many projects in future.

Indus River one of the NW Himalayan rivers with its tributaries is the single most important and major source of hydropower development in Pakistan. Soon after the signing of Indus Water Treaty between Pakistan and India in 1960, the construction of Tarbela dam as integral part of Indus Basin Project was initiated and completed in 1974. Mangla dam under the same treaty on the Jhelum River (also a Himalayan river) was completed in 1968. Recently under its "Vision 2025 Program" the Water and Power Development Authority (WAPDA) in Pakistan has initiated many small and medium sized hydropower projects in the region and many large projects are anticipated. The Warsak dam was completed in year 1955 on Kabul River. For these dams the concrete aggregates were derived from the respective river beds on which they are constructed. After decades of construction, the service performance of these aggregates is available and discussed.

This paper highlights the review of findings of the in-service performance of aggregates derived from the NW Himalayan rivers at three dams and provides general guidance to geologists, engineers and investors for selection of materials involved in future development projects.

BACKGROUND OF ALKALI-SILICA REACTION

There has been enormous volume of reported literature about the background theory and cases of Alkali-Silica Reaction in concrete structures after its discovery by Stanton in California, USA in 1940.

Alkali-Silica Reaction is a reaction in which certain aggregates react with the alkaline pore solution of concrete and manifests itself in extreme cases in the form of deterioration and distress in concrete. As the reaction's name implies, the reactive aggregate contains silica. However not all siliceous aggregates are reactive in terms of ASR. Only the amorphous non-crystalline/glassy form of silica, unstable crystalline polymorph of silica, poorly crystalline form of silica and microcrystalline quartz bearing rocks are reactive in concrete alkaline environment. The list of reactive minerals/rocks is long and available in literature.

The ASR in concrete structures is a global problem irrespective of geographic locations and climatic conditions. A worldwide listing of 76 known cases of alkali aggregate reaction in hydraulic structures is available (Charlwood and Solymar, 1994)[1].

The history of reported ASR cases in Pakistan is not much old as compared to other countries; however the studies in relation to finding the potential alkali susceptibility of concrete aggregates before using them in concrete at major dam projects are in practice since 1960 (TAMS, 1965; Stranger, 1960 and 1962; Sandberg, 1998)[2,3,4].

The first case of ASR in any hydraulic structure in Pakistan was reported by Mielenz (Petrographic examination of samples of concrete, Tarbela Dam, Pakistan, unpublished report for WAPDA). Later on another case was confirmed by Golder Associates (1983) at Warsak dam. Recently the studies related to ASR have been completed for raising of the existing 35 years old Mangla dam and a free ASR behavior is reported (Bhatti et al, 2005)[5].

The common feature of all the three above dams is that the concrete aggregates used belong to the same provenance i.e., gravels of NW Himalayan streams. The reserve of aggregates from this provenance is colossal and has huge economic viability for the hydropower development projects. It is envisaged that the millions of tons of concrete aggregates from these sources would be exploited in years to come for production of concrete.

At any location on the stream, the upstream geology and transport distance are the factors responsible for type and quantity of various rocks available in stream bed load. The geology alone is the single most important factor that needs to be considered in relation to ASR if the material is to be used in concrete.

REGIONAL GEOLOGICAL SETUP OF HIMALAYAS

The Himalayan Range is a singular unit of immense physical dimension flanking northern side of many countries of south Asia. The range pertains to the north-south traverse section and east-west longitudinal section. Geographically the Himalayan Range is divided into three parts i.e, Eastern, Central and Western units. On the basis of geological setting the whole of the range has been divided into three units which are equally applicable to each of the geographic sub-divisions.

The well-recognized geological units rising en echelon from the south to north are the Siwalik (Sub-Himalaya), Lesser Himalaya, and Higher Himalaya or Greater Himalayas. The Siwalik Range also called the Sub Himalaya, is the youngest of all, and abuts the plains as foothills dipping to the north. It extends from Indus almost to the Brahamputra with one gap of over 3000 km where the fierce monsoon erosion has almost worn it away completely. The second, the Lesser Himalaya, is older and higher than Sub Himalaya, but with the same strike alignment. The structure is more complex, being contorted by uplift into recumbent fold with older sedimentary rocks overthrusting younger ones. The Higher Himalaya, the axis and crystalline core of the whole range, is composed mainly of granites and gneisses with some meta-sedimentary rocks.

THE NORTHWEST HIMALAYA AND KOHISTAN ISLAND ARC

The northwest part of Himalayas forms the leading edge of Indian plate. The area represents the mountain chains, suture zones representing many large scale thrust faults (i.e, Main Mantle Thrust and Main Karakorum Thrust) due to Indian and Eurasian plates' collision. Geographically the area occupies a large part of the State of Jammu and Kashmir, Northern Pakistan and some part of Afghanistan as shown in Fig. 1 and 2. The rock types exposed in various geological subdivisions of Northwest Himalayas are as shown in Fig. 3. Photomicrographs of some of the rock types are shown in Fig. 4.

MAJOR NW HIMALAYAN RIVERS

The Indus River rises in the Tibetan Plateau north of Lake Manasarowar, at elevation 18,000 feet (5500 m) in the Kailas Glacial Range. The catchment of Indus at Tarbela dam covers nearly all the geological sub-divisions of NW Himalayas except Outer or Sub Himalaya. The catchment of Kabul river is not as large as the Indus but this consist of areas occupying Kohistan Island Arc, Higher Himalaya, Lesser Himalaya Indus Suture Zone and Asiatic Plate.

The catchment of Mangla dam occupies the Jhelum, Neelum, Kunhar and Poonch rivers. The Kunhar and Neelum rivers flow through Higher Himalaya, Lesser Himalaya as well as Sub Himalaya where they join with the Jhelum river. The Poonch river drains Lesser and Sub Himalayan terrain. The Jhelum River itself originates from Lesser Himalaya. However upstream of Mangla dam 120 km stretch of the river flows in sub Himalayan terrain. The geological domains through which these three rivers flow have been shown in the Fig. 1and 2.

PETROGRAPHIC MODALS OF AGGREGATES AT THREE SELECTED DAM SITES

Petrographic studies of samples from the river bed of three dam sites were carried out as per ASTM C 295. The concrete cores of three dams were also obtained and studied petrographically. The results of these studies have been given in Table 1 and 2.

CASE STUDIES

The following paragraphs represent the in-detail history of using these aggregates together with observations and conclusions drawn from the in-service behavior of concrete at three dams and providing the guidelines for future usage of these sources of concrete aggregates.

Warsak Dam (1960)

Project History

Warsak dam is a multipurpose project for irrigation and power generation on Kabul River, in North West Frontier Province (NWFP) of Pakistan commissioned in 1960. The dam is a concrete gravity structure rising 76m above the foundation level and 180m long with a generating capacity of 40MW.

The Concrete and ASR Studies

The concrete for dam and powerhouse structure was manufactured using the coarse and fine aggregates taken from the bed of Kabul River.

Cracks in the concrete of powerhouse started appearing in 1962 just after two years of completion and remained under observation by WAPDA. Extensive monitoring was started in 1975 and in 1982 M/s Golder Associates confirmed the presence of ASR in concrete. An emergency repair of ASR affected concrete was undertaken when a large number of

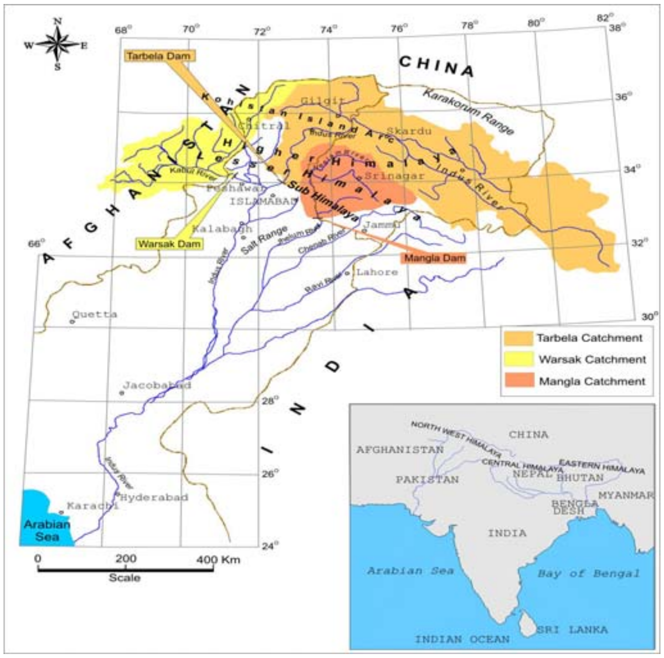


Fig. 1: Location of Tarbela, Warsak and Mangla dam with their respective catchments in NW Himalaya

rivets sheared in upstream connection of the valve of Unit No. 1 to the 18 feet diameter penstock, with the consequent major leakage of penstock water into powerhouse (CIDA, 1992)[6].

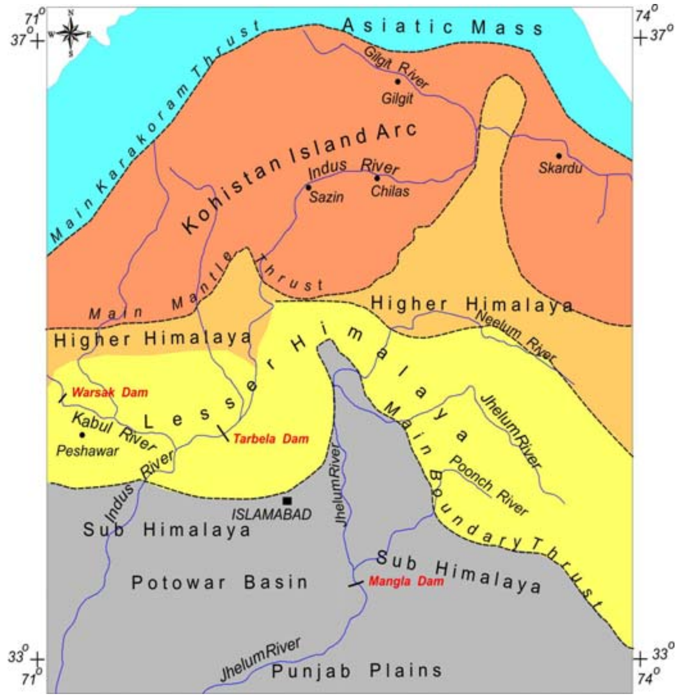
Water and Power Development Authority (WAPDA) appointed the Canadian International Development Agency (CIDA) to rehabilitate the affected units 1 to 4 of the powerhouse. The agency retained the services of Bureau d'Etudes de Lingnes de Transport inc. (BELT) to carry out the engineering, procurement and supervision of site work needed to modify and to repair the powerhouse concrete structure to counter the affects of AAR present at that time and anticipated in future. A joint venture of BELT and National Engineering Services Pakistan (NESPAK) completed the repair task in year 1992.

Petrographic modal analysis of concrete cores taken from powerhouse area revealed that about 38% of the total coarse and approximately of same percentage fine aggregate used were reactive in term of ASR.The major reactive species are slate/phyllite, greywacke, schist/gneiss and quartzite having microcrystalline and strained quartz. The studies conducted concluded that the slate / phyllite, greywacke, chert, and quartzite are the major contributor to ASR malady in Warsak's powerhouse concrete(Chaudhry and Zaka, 1994)[7]. The former two rocks were not fully metamorphosed to a degree where the rocks reconstitute into a stable metamorphs in terms of ASR.

Tarbela Dam (1971)

Project History

The dam is a multipurpose project as for irrigation and hydropower generation. The investigations for Tarbela Dam were started by the Government of Pakistan with the help of Messrs. Tiptoon and Hill Consulting Engineers (USA). In February 1960, TAMS of USA was appointed as project



consultants to the TDO (Tarbela Dam Organization) for the site investigation, project planning, preparation of detailed designs and supervision of project construction.

In 1965 tender was announced and contract for main engineering works was awarded to Tarbela Joint Venture (TJV), a consortium of thirteen European firms led by Impregilo. The construction was started in October, 1968 and principal structures were completed by July 1974.

The Concrete and ASR Studies

Coarse as well as fine aggregates were derived from the River Indus and used for the production of concrete. The material was declared harmless at the time of construction. The first appearance of ASR appeared in service spillway chute and in the auxiliary spillway. The irrigation tunnel structure showed extensive cracking.

The ASR in Tarbela dam was first reported by Melienz (unpublished report) after three years of completion. Later on after 11 years of construction ASR was reported in some structures and was thoroughly investigated (Chaudhry and Zaka, 1994)[7].

Mangla Dam (1967)

Project History

Studies for constructing a dam on Jhelum River were initiated in year 1951 by the Punjab Irrigation Department. In 1952 Tippon & Hill of USA as consulting engineers investigated the feasibility of dam at Mangla.

After its establishment by Government of Pakistan, the Mangla Dam Organization (MDO) appointed Binnie and Partners of UK as consultants to carry out detailed investigations. Harza Engineering Company International of USA and Preece Cardew and Rider of UK were associated with Binnie and Partner and designed the main spillway and engineering of electrical and mechanical equipment. In 1960, the construction of Mangla dam was awarded to a consortium of 7 firms lead by Guy of Atkinson. The construction work was completed in 1967 one year ahead of scheduled time.

The main feature of the project included an embankment with a maximum height of 138 m and a total length of 13 km, two spillways and a powerhouse. The raising of Mangla dam is now in its implementation stage. The feasibility and detail design for raising has been completed by Mangla Joint Venture (MJV), a consortium of seven local and two foreign consultants (MWH) and Black and Veatch (BV) lead by NESPAK.

The Concrete and ASR Studies

Approximately 1.6 million cu. m of concrete was placed in the concrete structures of Mangla dam. The aggregates used for this concrete were obtained from the Jhelum River deposits downstream of the main dam. Both the fine and coarse aggregates were declared harmless on the basis of mortar bar NBRI test (Stranger, 1961)[] and no maximum limit of alkalies in cement was specified.

The visual surveys during many periodic inspections revealed an ASR free concrete having no appreciable distress, cracking and other ASR related symptoms. Due to the positive indications of ASR free behaviour of Mangla concrete no attempt was made and nor it was found necessary to study the in-service performance before year 2004.

However for raising of existing spillway it was found necessary to ascertain the durability of 35 years old concrete. An investigatory programme comprising many destructive and non-destructive tests including petrographic evaluation of concrete was executed (Bhatti et al., 2005)[7].

DISCUSSION AND CONCLUSIONS

Alkali-silica reaction potential in aggregates derived from the NW Himalayan Rivers has been discussed. Major rock types contributing to the potential for ASR in concrete are identified and their in-service behavior has been evaluated through petrographic analysis and condition survey. It is generally inferred that:

1. All reactive constituents in river bed material originating from these streams are categorized as slow/late expanding.
2. In litholgical characteristics the aggregates are the same but vary in percentage. The fluctuation in percentage is due to the influence of local geology.

Comparing the three cases it is evident that most severe reaction took place at Warsak powerhouse area. The petrographic modals derived from concrete cores and borrow areas show that higher percentage of slate/phyllite and schist/gneiss are two groups that differentiate this modal from the Tarbela and Mangla.

At Warsak Dam the slate/phyllite and greywacke in the gravel source belongs to provenance having rock type of very low grade metamorphism. The metamorphism occurred to a degree where no reconstitution of minerals took place and therefore remained harmful (Chaudhry and Zaka, 1994)[8]. This together with the other rock types containing slowly reactive phases i.e., strained quartz were responsible for ASR. The XRD humps of greywacke show the absence of montmorillonite clay, so that the micro-crystalline matter had been the causative factor of ASR.

Alkali-Silica Reaction in some concrete structures of Tarbela Dam was the result of greywacke and rocks containing micro and cryptocrystalline silica. At the detailed design stage both the rock types were declared innocuous on the basis that the rock types have metamorphosed to a degree where reconstitution of minerals took place. However the detailed petrographic analysis by Chaudhry and Zaka, 1998, demonstrates that no reconstitution took place and the rocks were potentially deleterious.

While in case of Mangla dam, reaction has been detected only along some cracks but most of the concrete is ASR free. The possible reason of ASR along some cracks is due to localized concentration of alkalies. Through the analysis of concrete cores it is evident that more than 90% of aggregates used for production of concrete were reactive in terms of ASR, with the results that the reaction took place outside the passimum curve, which is a possible reason of ASR non-occurrence. We conclude that the reaction at Tarbela and Warsak took place due to a balancing amount of available alkalies and reactive aggregate in source.

In severity of ASR occurrence, Tarbela stands in-between the Warsak and Mangla. The total percentage of reactive material in case of Warsak and Tarbela is the same but with different individual constituents percentages. It is now believed that if we assume the other conditions conducive for initiation of ASR are alike for both the dams then the only difference is the occurrence of higher amount of slate/phyllite in Kabul River aggregate as compared to Indus at Tarbela.

The source of aggregate consisting variety of rock types possesses special problem i.e., no single passimum curve may derive which may be applicable to the source aggregates. The fluctuation in the percentage and size of reactive materials in the source results in hindering the establishment of a single passimum curve and so a safe limit of reactive aggregates in source. In the absence of such a curve measuring the reactivity potential of the aggregate through some quantitative tests is required. But evaluating the reactivity of aggregates remained a problem since after its discovery. Some tests conducted in the past have now lost their significance. The ASTM C-1260 which is now-a-days in practice is somewhat conservative in predicting the ASR potential of aggregates.

In such cases it is prudent to take help from the existing structures where the same source has been used. The performance record provides best judgment of aggregate's potential reaction by alkali silica reaction. The survey of exiting concrete structures in the close vicinity of any proposed project where the similar source had been used provides valuable information. Experience with the ASR related study of gravels of NW Himalayas shows that this statement is not always correct. Declaring the river bed material reactive in one certain stream might not be applicable to tributaries of the same stream.

It is recommended that if no precise service record is available, a comprehensive petrographic analysis supplemented by other techniques should be conducted for ASR susceptible material.

Fig. 2: Geological Subdivisions of NW Himalayas

Geolgical Subdivision	Sub Himalaya	Lesser Himalaya	Higher Himalaya	Indus Suture Zone (Main Mantle Thrust)	Kohistan Island Arc	Shyok Suture Zone (Main Karakoam Thrust)	Asiatic Mass
Rock Types	Sandstone	S-type Granitoids	S-type Granitoids	Basic Mylonite	Amphibolite	Perodotites	Hard Schist / Slate
	Claystone	Hard Schist	Migmatities	Serpentinised Peridotite	Acid to Intermediate Volcanics	Greenstone	Phyllite
	Conglomerates	Quartzites	High Grade Calc Pelites	Gabbros	I - type Granotoids	Flysh / Chert	Calc Pelites
		Slate	Amphibolite	Greenstones	Volcanogneic Arenites	Acid to Intermediate Volcanics	Marble
		Phyllite	Hard Schist	Flysh & Chert	Gabbronorites	Basalt	Granitoids
		Greywacke	Marble		Diorites		Amphibolites
		Limestone			Basalt		
		Shale					
		Sandstone					

Potentially Deletrious Constituents in terms of ASR

Figure 3: A matrix of geological subdivisions of NW Himalayas and rock types of respective sub-division

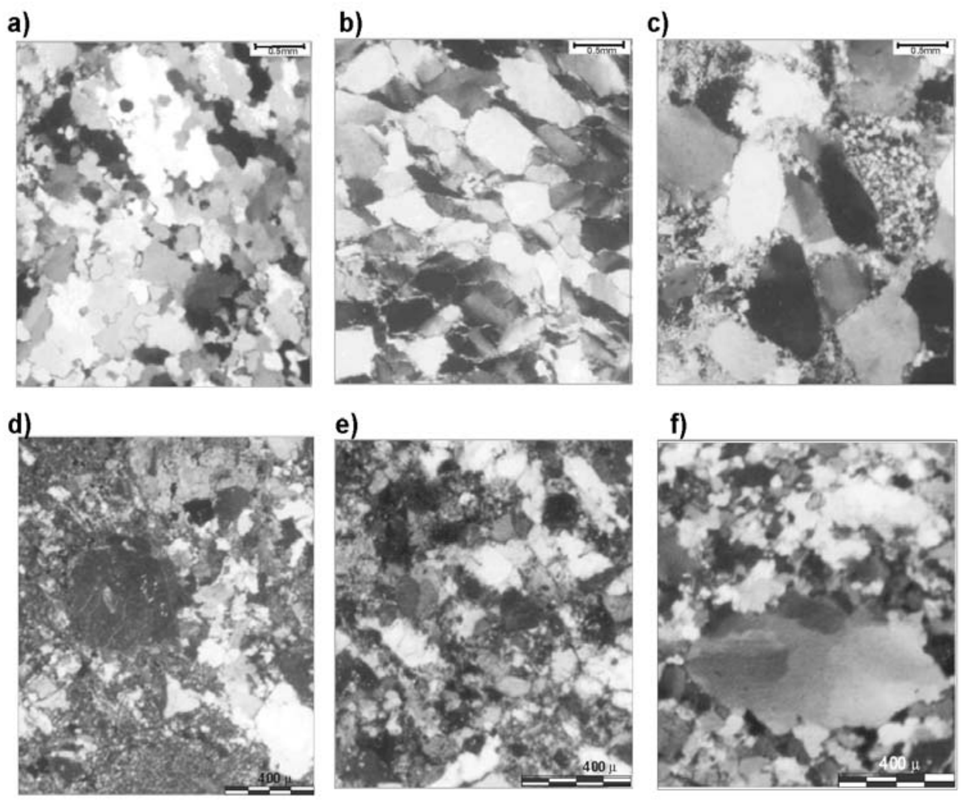


Figure 4: Photomicrographs of some of the reactive rock types a, b) quartzite with stained quartz c), greywacke with microcrystalline matrix in Jhelum River originating from Lesser Himalaya d), acid to intermediate volcanics with glassy to microcrystalline matter e), greywacke f), granite from Higher Himalaya with highly strained quartz

Table-1: Petrographic Modal Composition of Three Rivers Bed Gravels and Coarse Aggregates in Concrete

Mineral / Rock Constituents	*Indus River at Tarbela* ***(n=12)***	*Kabul River at Warsak* ***(n=10)***	*Jhelum River at Mangla* ***(n=6)***	*Tarbela Dam* ***(n=8)***	*Warsak Dam* ***(n=10)***	*Mangla Dam* ***(n=10)***
	Gravels			**Concrete Coarse Aggregate**		
Micro Fractured and Strained Quartzite*	5.3	9.6	62.2	5.8	8.7	61.8
Quartzite	19.9	19.5	-	21.5	18.2	-
S-Type Granite*	7.0	6.3	4.0	6.5	6.5	-
I- Type Granite	8.5	5.0	-	8.1	6.1	-
Diorite / Microdiorite	19.4	12.1	0.8	18.8	14.0	-
Slate / Phyllite*	1.7	6.9	0.4	2.0	5.9	-
Quartzwacke *	-	-	2.2	-	-	-
Lithic Arenite*	-	-	2.0	-	-	-
Greywacke Group*	8.1	3.3	1.3	7.6	3.5	13.3
Limestone + Marble	5.4	5.3	0.4	3.0	5.1	2.1
Acid to Intermediate Volcanics*	10.6	3.4	22.5	11.2	3.8	13.7
Basic Volcanics	3.0	1.5	-	2.7	2.0	-
Vein Quartz	0.1	0.2	0.2	0.1	0.1	-
Chert/Jasper *	0.3	0.8	0.5	0.4	0.5	3.9
Dolerite	0.2	0.1	-	0.3	0.2	-
Schist / Gneiss*	2.0	8.8	-	2.4	7.0	0.8
Microgabbro	-	-	0.6	-	-	-
Basalt	-	-	0.5	-	-	1.6
Microgranite	0.5	0.2		0.6	0.3	-
Metadolerite	-	-	1.8	-	-	2.8
Amphibolite + Garnet Amphibole	3.5	15.2	-	5.2	16.8	-
Granite Mylonite*	3.3	1.7	0.24	2.7	1.3	-
Sandstone	1.0	-		0.8	-	-
Epidosite	0.2	0.1	0.2	0.2	Traces	-
Total Deleterious Constituents	**38.1**	**40.8**	**96.0**	**38.6**	**37.2**	**92.7**

Minerals / rocks marked with asterisk sign(*) are potentially reactive.

Table-2: Petrographic Modal Composition of Three Rivers Bed Sands and Fine Aggregates in Concrete

Mineral / Rock Constituents	*(Indus River) Tarbela Dam* ***(n=12)***	*(Kabul River) Warsak Dam* ***(n=10)***	*(Jhelum River) Mangla Dam* ***(n=2)***	*Tarbela Dam* ***(n=8)***	*Warsak Dam* ***(n=10)***	*Mangla Dam* ***(n=6)***
	Sand			**Concrete Fine Aggregate**		
Quartz	30.4	31.2	36.5	28.2	30.0	38.3
Amphibole	6.8	8.2	1.2	6.0	7.2	0.4
Plagioclase/Albite	6.0	7.0	3.6	6.2	6.5	1.5
Orthoclase/Microcline	2.3	4.8	-	3.0	4.7	1.6
Magnetite	1.3	1.1	1.1	1.5	1.4	1.5
Biotite + Muscovite	6.2	4.2	1.9	6.8	5.2	3.0
Strained Quartz	7.1	4.0	-	6.5	6.0	-
Chlorite	0.3	0.6	0.3	0.2	0.3	-
Greenstone	0.5	0.8	-	0.6	0.5	-
Garnet	0.3	0.5	0.8	0.2	0.3	-
Sphene	0.2	0.2	-	0.1	0.2	-
Tourmaline	0.2	Traces	0.1	0.2	0.1	0.2
Lithic Arenite	-	-	0.4	-	-	-
Strained Quartzite	2.5	2.7	18.7	2.0	3.0	23.2
Quartzite	5.2	5.8	-	6.3	6.2	-
S-Type Granite	2.1	1.1	-	2.3	1.0	-

Diorite +Microdiorite	5.2	4.3	-	4.8	5.0	-
Phyllite/Slate	3.5	1.8	5.8	2.8	2.0	4.6
Greywacke Group	5.0	0.5	0.5	6.0	0.7	5.2
Limestone + Marble	1.2	2.7	20.8	1.5	3.0	6.2
Acid to Intermediate Volcanics	0.6	1.1	3.5	1.3	0.8	6.9
Chert / Jasper	0.2	0.5	0.2	0.5	0.7	4.1
Dolerite	0.1	0.2	-	0.2	0.3	-
Schist/ Gneiss	2.1	3.2	1.3	1.7	2.8	1.9
Basic Volcanics	0.7	1.6	-	1.0	1.3	-
Sandstone	Traces	-	-	Traces	-	-
Amphibolite + Garnet Amphibolite	3.5	6.2	-	3.5	7.1	-
Granite Mylonite	2.4	0.8	-	2.0	0.5	-
I-Type Granite	3.6	3.0	1.4	3.3	3.0	-
Microgranite	0.8	1.9	-	1.2	0.4	-
Epidosite	0.2	Traces	1.7	0.1	0.2	1.3

Minerals / rocks marked with asterisk sign (*)are potentially reactive.

The potential risks involved in using these aggregates for new construction can be minimized by taking preventive measures. One such measure is using the pozzolanic materials. The mixing of inert material is not advised, since this may aggravate the potential and shifting of expansion on the passimum peak. On small jobs or situations in which the pozzolanic materials are not available economically but made part of specifications only to curb the potential risk of ASR it is recommended to develop a quarry in innocuous rocks.

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