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ALLAI AGGREGATE FOR REHIBILITATION AND RECONSTRUCTION OF OCTOBER 8, 2005 EARTHQUAKE AFFECTED ALLAI-BANAN AREA, NWFP, PAKISTAN

BY

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Abstract: *The October 8, 2005 earthquake destroyed infrastructure of Allai-Banan area and large quantity of aggregate is required for the relocation, restoration, construction of buildings, bridges and roads. Moreover a number of hydroelectric projects with a total hydroelectric potential between 500 to 1000 MW are likely to be built on the Allai river and its tributaries that will require hundreds of thousands of cubic meter of fine and coarse aggregate. The Allai river and its tributaries flow across the Higher Himalaya, igneous and metamorphic rocks of the Lesser Himalaya, Tethyan Himalaya, Indus Suture Zone and part of adjoining Kohistan Island Arc and contains substantial quantity of aggregates that can be utilized for construction. The geology of the area reveals a very complex lithostratigraphic and lithotectonic set up that explain a very heterogeneous nature of aggregates derived from this terrain.*

Engineering properties of the gravel and associated sand deposits of Allai river, terraces, bars and its tributaries fulfill the parameters specified in the standards. However, the aggregates of Allai river system contain mylonites, slates, phyllites, microcrystalline quartz and highly strained quartz. These potentially reactive rock types can initiate alkali aggregate reaction that will damage the infrastructures if preventive measures are not considered.

INTRODUCTION

Allai valley located at lat. 34° 50′ 14″ and long. 73° 04′ 08″ (Toposheet No. 43 F/1) is one of two thesils of district Batgram. The valley is accessible from Besham via Kond Saiyidan and Thakot located on Karakoram Highway and its width varies from 0.5 km to 5 km. Allai river, main stream of the area, confluences the River Indus near Besham at Kond Saiyidan. The October 8, 2005 earthquake (Ahmad et al., 2008; Mona Lisa et al., 2008) destroyed the built infrastructure leaving devastating impacts on human life in northern Pakistan including Allai and its union council Banan. Earthquake rehabilitation and reconstruction programme of Pakistan's Government aims at improving the lives of quake-ravaged people and construction of buildings, schools, dispensaries, hospitals, roads and bridges, etc.

In the areas of Allai-Banan, huge quantity of aggregate will be required for the relocation, restoration, construction and modernization of civil infrastructures. In addition to this, a number of hydroelectric power projects with a total hydroelectric potential of 500 to 1000 MW are likely to be built on the Allai river and its tributaries that will require hundered of thousands of cubic meter of fine and coarse aggregate for the weir/dam and related civil structures. The gravel and associated sand occurs in the bed of the Allai River and its tributaries near Allai and Banan. Besides gravel and sand deposits of river and its tributaries, coarse aggregate can be manufactured by crushing suitable rock types (Bell, 2007) to meet the demands of civil works.

In service performance of civil infrastructure depends on a number of factors (Sarkar and Actin, 1990; Neville, 2000; Ilangovana et al., 2008) that may include engineering properties of coarse and fine aggregates, proportion of aggregate and cement paste, paste-aggregate bond characteristics, etc. In this context, durable aggregate is preferred that may have the ability to maintain its engineering properties without momentous deterioration in strength during an extensive period of time (Neville, 1981; Lafrenz, 1997; Smith and Collis, 2001). Along with suitable physical and mechanical properties, it is indispensable that the aggregate should be innocuous with respect to deleterious alkali aggregate reaction potential (ASTM C 295, Bell, 2007) especially where it has to perform in humid conditions. In Pakistan, aggregates for construction are manufactured by crushing rocks extracted from outcrops (Tepordei, 1999; Ahsan et al., 2000; Gondal, 2006a, b) through open excavation. In addition to this crushed and uncrushed river, terrace and pit run gravels (Chaudhry et al., 1997; 2001) and in some cases recycled aggregates (Deal, 1997; Wilburn and Goonan, 1998), consisting mainly of crushed concrete and asphalt pavements, are also used when crushed rock aggregate is not available or is economically unsuitable.

Deposits of sand and gravel (Collins and Dunne, 1990; Kondolf, 1997; Bolen, 1999) are widely exploited as construction aggregate for reinforced concrete, concrete products (such as blocks, bricks, pipes, etc), plaster and gunite sands, roofing granules, road pavements, riprap, railroad ballast and filter blankets for drainage through out the world (Bell, 2007). These fluvial deposits have been subjected to lengthy transportation processes (e.g. abrasion and attrition) in streams that remove all the weak materials leaving behind durable, sub rounded to rounded and well sorted gravels (Barksdale, 1991). Generally these graveliferous aggregate deposits can be quarried from river beds, flood plains and river terraces. In Allai area, floodplain and channel deposits are topographically lowest areas along river and tributaries beds that contain substantial quantity of aggregates as active and abandoned channel fill, small alluvial fans and bar deposits. Thickness and horizontal extent of the deposits varies considerably and is paleo-topographically controlled. Besides these, few terrace deposits, such as Banan Terrace, are located at higher elevations and present day river channel is cutting through these. The depth of incision by river itself and its tributaries varies from point to point. Alluvial fans and bars are few in the area and predominantly contain gravels.

The Allai river and its terraces are the only potential resource, keeping in view apparent quantity and close proximity to transportation routs, economics and end users, for the development of gravel and sand quarries in the area. However, for extraction of aggregates from these prospective deposits some processing will be required. At places minor over-burden and/or vegetation occurs but can be removed. The boulders and gravels will require crushing to meet up the specified gradation, texture and grain morphological parameters. From gravel fans and terraces, aggregates can be transported to Allai for crushing and sizing. The crushed gravel can be sized by using vibratory sieves so that high efficiency and capacity are met. The sieved out as well as oversized material may require the removal of deleterious materials like clay, mud and organic matter, etc.

The present study is mainly aimed:

- to locate the potential resources of sand and gravel for the remote area of Allai and Banan,
- to find out the engineering characteristics of Allai river aggregates,
- to determine the modal mineralogical composition of fine and coarse aggregates,
- to properly investigate and recognize potentially reactive aggregates prior to construction and
- to suggest the remedial measures to avoid the deleterious alkali aggregate reaction.

Representative samples for the evaluation of physical, petrographical and chemical properties of Allai aggregate were collected from river bed, terraces and bars.

ORIGIN OF AGGREGATES

Allai river and its tributaries flow across the Higher Himalaya, igneous and metamorphic rocks of the Lesser Himalaya, Tethyan Himalaya, Indus Suture Zone (ISZ) and part of adjoining Kohistan Island Arc. The Allai river drainage system derives S-type porphyritic cordierite bearing two mica granites, high grade pelitic and psammitic schists, pegmatites, vein quartz and dolerites/metedolerites from Lesser Himalaya igneous and metamorphic zones which lies between the Punjalt Fault and Main Central Thrust (MCT; Chaudhry and Ghazanfar, 1990). The non-porphyritic garnetiferous granites, quartzites, marbles, pelites, psammites metedolerites (amphobolites) and pegmatites are derived from the upper amphibolites facies of the Higher Himalaya. Slates, phyllites and slightly metamorphosed limestones are derived from fault slices/zones of the upper Mesozoic and lower Paleozoic Tethyan sediments. This zone that lay between Thakot Fault and ISZ is now imbricated. In addition to these rock types, dunites/peridotite and basic rock fragments as well as meta-argillites are derived from the ISZ. Amphibolites, diorites and norites have their origin in the Kohistan Island Arc that lies north of the ISZ.

GEOLOGY OF THE AREA

The area of Allai-Banan is situated on eastern and northeastern part of the Besham Syntaxis (Treloar et al., 1989; Williams, 1989). The Besham Syntaxis is one of the many domal structures of the Higher Himalaya and is bounded on the east by Thathakot Fault and on the west by the Puran Fault (Chaudhry et al., 1980). Both, Thathakot and Puran faults trend NS. The lower Proterozoic Higher Himalaya Crystalline (HHC) comprises upper amphibolite facies, peleites, psammites, quartzites and marbles along with garnet mica non-porphyritic granitoids (Chaudhry et al., 1994). The HHC structures in this region lay NS as against EW predominant trend in the Lesser Himalaya (Chaudhry et al., 1997).The area has suffered lower Proterozoic, Pan African and Himalayan orogenies in which gneisses and mylonites were developed.

The Lesser Himalaya drained by Allai river system is composed of peletes, psammites and S-type porphyritic two mica tourmaline and cordierite granites. The Lesser Himalaya suffered Pan African orogeny and developed mylonites during Himalayan orogeny.

A unique feature of this area is a kidney shaped outcrop of the Tethyan Himalaya. The Tethyan Himalayan sediments are only slightly metamorphosed and comprise limestones, meta-argillites (slates and subphyllites). This zone that lay between the Trans Hhimadri Fault and the ISZ is now imbricated. The Tethyan Himalaya has been discussed in detail by Ghazanfar (1993).

The structural zone (ISZ) in Allai is a rare and unique section in the sense that in addition to ultramafics and pillow basalts, it also contains low grade siliclastics mete-turbidites deposited in the fore arc basin. To the north of this fore arc basin lies the deeply eroded parts of Kohistan Island Arc. The Allai river system cuts across the amphibolites, diorites and barely accesses norites.

The brief description of geology of the area given above reveals a very complex lithostratigraphic and lithotectonic set up (Treloar et al., 1989; Williams, 1989) and helps to explain a very heterogeneous nature of aggregates derived from this terrain. The geology may vary from one tributary to the other. Therefore, the aggregate deposits may vary widely in comparison and physical properties. However, in this publication by far the biggest and better mixed deposits of Allai-Banan area were studied.

ENGINEERING CHARACTERISTICS OF COARSE AGGREGATE

As engineering properties of aggregates determine their performance in mortar, concrete and unbound and bound pavement (e.g. Neville and Chatterton, 1981; Winslow 1994, Pigeon and Plateau, 1995; Neville, 2000; Smith and Collis, 2001) therefore it is common practice to work out desirable properties through tests mentioned in literature (e.g. Neville, 2000) standards (e.g. BS, ASTM, etc.).

Texture and Grain Morphology

Surface texture plays a vital role in bond between aggregate and cementing material and depends upon the mineralogy of the aggregate particle. Generally, the aggregate with rough surface texture is desired in engineering projects (Nevelli, 2000; Fletcher et al., 2002) as it produces a stronger bond thereby creating a stronger cement concrete or hot mix asphalt concrete and avoid stripping of asphalt (Maupin, 1987). Aggregate particles of the Allai river do not indicate considerable variation in surface texture and dominantly texture is rough. Aamphibolites, diorites, granite, S-type granite gneiss, granite mylonites, mylonites, pegmatites, schists, vein quartz, norites and dunites show rough texture whereas marbles give smooth texture.

The gravel of the Allai river consists of naturally rounded particles resulting from disintegration and abrasion of parent rocks. They present three aspects of grain morphology that include shape, sphericity and roundness. Allai aggregates are subangular to well rounded (Pettijohn, et al., 1987; Ahn, 2000; Tucker, 2001; Neville, 2000) and generally they show low to high sphericity. The morphology of grains depends on mineralogy, degree of weathering and degree of abrasion during transportation (Ritter, et al., 2000; Bell, 2007). Rounded particles are undesirable in cement and asphalt concrete as they impede the bond between aggregates and cementing material (Hu and Stroeven, 2006). In addition to this rounded aggregate continue to compact, shove and rut after construction. Similarly, elongated and flat particles break under impact and reduce strength (Smith and Collis, 2001; Jamkar and Rao, 2004). In present case, Allai aggregate is predominantly angular to rounded and degree of sphericity is low it may, therefore, prove a good aggregate for cement and asphalt concrete. However, crushing is recommended prior to its use in construction and it will help to get the desired gradation.

Bulk Density and Specific Gravity

It gives the mass of the aggregate in given volume and is required for the volume method of mixture proportioning (Neville, 2000; BS 812). The well-graded and densely packed aggregates have higher value of the density as compared to loosely packed aggregates (Mehta and Monteiro, 1993). The values of loose bulk density range from 89 lbs/cft to 91 lbs/cft. Specific gravity gives a weight volume relationship so that an appropriate concrete design mix can be determined (AASHTO T 85). The specific gravity of Allai aggregate on oven-dried basis is 2.70. The use of bulk density has declined due to availability of mix designs (Smith and Collis, 2001).

Water Absorption

The water absorption affects the specific gravity of the aggregate as well as in service behaviour of concrete. It is considered an indirect measure of permeability of aggregate that affects other physical characteristics such as mechanical strength, soundness and its general durability potential (Smith and Collis, 1993; Neville, 2000). Aggregates having high water absorption are unsuitable unless they are found to be acceptable based on other properties such as strength, impact and hardness tests (Schmidt and Graf, 1972; Graf, 1986). The water absorption of the Allai river gravel varies from 0.9% to 1.1% that is within the specified limits.

Strength and Durability

Aggregates under go wear and tear through out their performance life and it is required that they should resist crushing, degradation and disintegration when used in sub base, base course, hot mix asphalt and plain cement concrete (Roberts et al., 1996; Wu et al., 1998). In addition to this aggregates should be resistant to abrasion and polishing otherwise they will cause skidding on the roads. Fookes et al., (1988) recommend using the combination of impact value and Los Angeles abrasion resistance to access the performance and durability of aggregates. In addition to this, work by Bullas and West (1991) shows that aggregate crushing value helps to separate suitable and unsuitable aggregate for bitumen macadam road base as compared to aggregate impact value.

Aggregate impact value (AIV) indicates relative measure of mechanical resistance of an aggregate to sudden shock (Smith and Collis, 2001). The percentage loss in Allai gravel is 25.3% and this value is within safe limits for concrete and asphalt. Another parameter to assess toughness and abrasion resistance of the aggregate is aggregate crushing value (ACV) and Los Angeles abrasion value, LAV, (Smith and Collis, 2001). The aggregate crushing value is 22.9% and Los Angeles abrasion value is 24.6% for Allai gravels that are within safe limits for construction purposes. Roberts et al., (1996) show values of 10% fines for igneous rock indicating %age loss of 27-49 for granite, 33-55 for gneiss and 20-35 for quartzites. Similarly, Bell (2007) indicates that AIV, ACV and LAV for basalt, granite, micro-granite and quartzite range from 12% to 20%. In this study ACV and AIV for quartzite and granite is 20% i.e. maximum. Although AIV, ACV, and LAV are within safe limits according to AASHTO and BS but they are high as compared to the values calculated by Bell (2007). This is probably due to the presence of mylonite, gneiss and schist clasts in Allai gravels.

Another parameter, soundness test (ASTM C 88), mentioned in published literature (e.g. Smith and Collis, 2001; Neville, 2000) is the resistance of aggregate to disintegrate when subjected to attacks by salts and freez and thaw action during extreme weathering conditions (Wu, et al, 1998; ASTM C 88). The loss of Allai gravel when tested in Na_2SO_4 solution (AASHTO T 104) ranges from 3.32% to 3.25% thereby indicating a sound aggregate for construction. In a study carried out for Albama, Georgia, North and South Carolina, aggregates mainly composed of granite indicate soundness value in the range from 0% to 2.2% (Cooley, Jr. et al., 2002). The values of Allai gravels are relatively high as it contains some weak rock clasts as mylonite, gneiss and schist clasts.

ENGINEERING PROPERTIES OF FINE AGGREGATE

The river bed and terraces contain variable amount of sand. It can be used in cement concrete, unbound and bound pavements after processing. Like coarse aggregates, many properties of the fine aggregate depend entirely on the properties of the parent rock, for example, chemical and mineral composition, petrologic character, specific gravity, hardness, strength, physical and chemical stability, pore structure and colour (Neville, 1981; Smith and Collis, 2001; Dilek and Leming, 2004).

A number of sieve analyses of the Allai River bed and associated sand deposits show that it does not conform to the overall limits of BS 882: 1992; ASTM C 33. The sand is poorly graded and its gradation varies from place to place. It is coarse grained (FM=3.8) where it occurs as point bar deposits and sand associated with terraces is fine grained (FM=0.9). The amount of fine aggregate, generally passing the #50 and #100 sieves, affects the characteristics of cement concrete like workability and bleeding (Dilek and Leming, 2004). Besides this, it is believed that appropriate quantity of fine aggregate is needed for good cohesiveness and plasticity (Quiroga and Fowler, 2003). Improved overall grading of sand can be achieved by blending experiments (Chaudhary et al., 2000; Ahsan et al., 2000). The sand for blending can be obtained as a by-product if coarse aggregates were manufactured by crushing innocuous oversized associated gravels.

The other properties of fine aggregate include bulk density (BS 812), specific gravity and water absorption (BS 812), soundness (ASTM C 33) and Los Angles abrasion value (ASTM C 131) are 85Lbs/cft-89Lbs/cft, 2.70-2.73, 0.5%-0.9%, 2.32%-2.96%, and 28.7%-29.3%, respectively. All these values are well below the time honoured standards that are referred in construction industry for specifications. However, Allai sand contains 1.21%-1.30% silt and clay and when tested in accordance to ASTM C 142, Allai sand contains 0.5% to 1.1% clay lumps. Such pieces may be problematic in concrete in cold climates. The sands contain dried leaves, wood pieces and grass shoots as organic impurities but are free from chloride contents ((Neville, 2000).

PETROGRAPHY OF COARSE AGGREGATE

ASTM C 295 recommends petrographic examination (Watters, 1969; Nixon and Sims, 2006; Tremblay, 2008) of aggregates to "determine the physical and chemical characteristics, identification of types and varieties of rocks present in potential aggregates, establish whether the aggregate contains chemically unstable minerals such as soluble sulfates, unstable sulfides that may form sulfuric acid or create distress in concrete exposed to high temperatures during service, or volumetrically unstable materials such as smectites and potentially alkali-silica reactive and alkali-carbonate reactive constituents, determine such constituents quantitatively, and recommend additional tests to confirm or refute the presence in significant amounts of aggregate constituents capable of alkali reaction in concrete". In addition to this petrography is implied to identify promising occurrence of contaminants in aggregates, such as synthetic glass, cinders, clinker, coal ash, magnesium oxide, calcium oxide, or both, gypsum, soil, hydrocarbons, chemicals that may affect the setting behavior of concrete or the properties of the aggregate (ASTM C 295). Moreover, animal excrement, plants or rotten vegetation, and any other contaminant that may harm the performance of concrete is also undesireable (Neville, 2000). For petrographic evaluation fine and coarse fractions (10 samples of each) of Allai aggregate were studied under the microscope to, particularly, predict in service performance of gravel and sand with respect to alkali aggregate reaction potential. The petrographic results of coarse and fine aggregates are presented in Table 1 and 2, respectively. However Table 2 show modal analysis of coarse fraction associated with fine sand.

The gravels of the river and its tributaries are composed of amphibolites, diorite, granite, S-type granite gneiss, granite mylonite, marble, mylonite, pegmatite, schist, vein quartz, norite and dunite. The fine fraction of river bed, bars and terraces is composed of granite/granodiorite, diorite/tonlaite/amphibolite, quartzite, phyllite/slate, greywacke group, chert, quartz mica schist/gneiss, quartz/polygrain quartz, feldspar, biotite, muscovite, amphibole, epidote, magnetite, garnet, tourmaline and zircon. In addition to this petrographic modal analysis of 6 samples was carried out and average composition of rocks present in these samples are: amphibolite (14.5%), diorite (25.1%), granite (13.81%), granite gneiss (4.0%), marble (10.3%), mylonite (3.5%), pegmatite (1.0%), schist (11.4%), vein quartz (1.3%), psammite(6.7%), slate(2.3%), greenstone/meta-basalt (3.8%), norite (2.0%) and dunite/peridotite (0.3%).

ALKALI AGGREGATE REACTION POTENTIAL

Alkali aggregate reaction (AAR) was first reported by Thomas Stanton (1940) as a reaction of alkalis released by cement paste (Na_2O and K_2O) and California aggregates that contained opal. This reaction later on named as alkali silica reaction (ASR) produces a gel that will expand in presence of moisture and induces cracks in aggregate and cement paste (Diamond, 1989; Hobbs, 1978, 1988; Swamy, 1992; West, 1996). ASTM C 33 indicates that alkali silica reactive constituents present in aggregates are opal, chalcedony, cristobalite, tridymite, highly strained quartz, microcrystalline quartz, volcanic glass, and synthetic siliceous glass. In addition to this aggregate materials containing glassy to cryptocrystalline intermediate to acidic volcanic rocks, some argillites, phyllites, graywacke, gneiss, schist, gneissic granite, vein quartz, quartzite, sandstone, and chert are also potentially deleterious with respect to AAR (Mindness and Young, 1981; Wenk, 1998; Codey et al., 1994; Gress, 1996).

Published literature indicates (Frany and Kosmatka, 1997; Chaudhry and Zaka, 1998; Neville, 1996, 2000) that ASR will not occur when the equilibrium internal relative humidity in the concrete is less than 75% (Pedneault, 1996), in the absence of sufficient alkali in the pore solutions (Nixon and Sims, 1992) and absence of pessimum proportion of reactive aggregates (CSA, 2000). Moreover, if any one of these three factors is absent, then ASR will not proceed (Stark, 1991).

In Pakistan structural damage in Warsak Dam was recognized due to the occurrence of ASR (Chaudhry and Zaka, 1998) and major repair of dam was carried out. Similarly, ASR in Tarbela Dam (TAM Report, WAPDA, 1965) damaged the power tunnels. In case of Warsak Dam aggregates containing potentially reactive volcanics were used with ordinary Portland cement (OPC) and in Tarbela Dam aggregate extracted frown the River Indus were involved in reaction with OPC, twelve years after completion. Chaudhry and Zaka (1994) petrographically indicated the presence of strained quartz and other rock types, particularly meta greywackes, that were slowly reacting with aggregates to produce ASR. Shrimer (2003) reported malfunction in gates of a 47 years old dam in southern British Columbia due to AAR and in all 125 affected sites have been identified through out Britsh Columbia. Mostly quartzite, andesite, chert and opal were identified to be involved in AAR (Shrimer, 2003).

Allai gravels contain mylonites and slates as deleterious constituents with respect to AAR. Coarser fragments associated with Allai sand that are potentially reactive are phyllite/slate, greywacke group and chert. It is evident from published literature (e.g. TAM Report, WAPDA, 1965; Charlwood and Solymar, 1994; Chaudhry

Table 1

Petrographic modal analysis of coarse aggregate of Allai gravel

Rock /Sieve	>2in	1 1/2 in	1 in	3/4 in	1/2 in	3/8 in	No. 4
Amphibolite	20.00%	9.10%	15.60%	12.00%	2.10%	10.00%	7.10%
Diorite	27.20%	24.40%	24.50%	31.50%	0.00%	28.10%	27.50%
Granite	5.00%	19.50%	8.20%	10.30%	10.20%	14.90%	10.40%
Granite Gneiss S-Type*	9.60%	4.90%	7.20%	4.30%	3.20%	4.00%	6.30%
Marble	7.50%	15.90%	17.20%	10.40%	22.30%	12.00%	10.10%
Mylonite*	3.20%	6.80%	2.50%	3.60%	2.30%	2.60%	3.00%
Pegmatite*	2.50%	2.70%	1.00%	2.30%	1.10%	2.10%	2.10%
Schist	1.10%	2.30%	20.50%	14.50%	18.50%	13.60%	14.90%
Vein Quartz	1.00%	0.00	2.50%	0.60%	1.00%	0.70%	3.70%
Psammite*	5.10%	9.50%	0.00%	5.40%	4.50%	8.30%	9.60%
Slate*	2.00%	0.40%	0.80%	1.20%	1.40%	3.70%	3.00%
Greenstone	5.60%	4.50%	0.00%	1.80%	5.00%	1.00%	1.10%
Norite	5.10%	0.00%	0.00%	0.00%	25.40%	0.00%	0.00%
Dunite	5.10%	0.00%	0.00%	2.10%	3.00%	0.00%	1.2%

*Potentially deleterious constituents with ASR potential

Table 2

Petrographic modal analysis of rock fragments associated with fine aggregate from Allai river

Rock fragments /sieve	NO.8	NO.16	NO.30	NO.50	NO.100
Granite/granodiorite	22.20%	22.10%	34.30%	42.00%	53.60%
Diorite/tonalite/Amphibolite	6.30%	8.30%	4.70%	4.60%	8.40%
Quartzite	1.50%	1.60%	1.30%	1.70%	2.00%
Phyllite/slate*	2.40%	1.40%	1.40%	1.60%	2.4%.
Greywacke group*	1.60%	3.70%	0.90%	2.30%	2.80%
Chert*	1.40%	1.50%	1.60%	1.80%	1.80%
Quartz mica schist/gneiss*	1.20%	1.30%	1.00%	1.40%	3.00%
Schist*	1.10%	1.20%	1.20%	1.40%	1.20%

*Potentially deleterious constituents with ASR potential

Table 2 (Cont.)

Petrographic modal analysis of fine aggregate from Allai river

Mineral grains/ sieve	NO.8	NO.16	NO.30	NO. 50	NO. 100
Quartz/polygrain quartz	23.50%	16.30%	9.60%	6.10%	0.90%
Feldspar	3.40%	4.90%	0.30%	0.50%	0.20%
Biotite	12.40%	9.90%	8.80%	8.10%	8.60%
Muscovite	15.50%	20.40%	17.00%	18.40%	7.20%
Amphibole	0.80%	0.40%	1.10%	0.40%	0.40%
Epidote	0.90%	0.10%	0.60%	0.50%	0.80%
Magnetite	5.40%	3.30%	8.50%	8.30%	8.10%
Garnet	0.00%	3.10%	7.10%	0.00%	0.00%
Tourmaline	23.50%	16.30%	9.60%	6.10%	0.90%
Zircon	3.40%	4.90%	0.30%	0.50%	0.20%
Clay lumps	12.40%	9.90%	8.80%	8.10%	8.60%

and Zaka, 1994; 1998) that use of these gravels will create a major durability crisis that will result in premature deterioration of concrete structures. The present study shows that Allai sands are deleterious as for as ASR is concerned. They contain more than 20% highly strained quartz. In addition to this, ASTM C 1260, quick mortar bar test shows an expansion of 0.30% at 28 days that verifies the conclusion of peterographic test, ASTM C 295.

As far as Allai aggregate is concerned it is the only source of aggregate available in the area of Allai and Banan. As the area is located in tectonically deformed Himalayan ranges and the aggregate is extracted from the rocks including granites, granodiorites, quartzites and metamorphic rocks such as slates, gneisses, etc. therefore it is not possible to avoid their use as aggregates. Moreover, if aggregate is transported from innocuous sources like limestones, cost of the project will increase manifolds. However, it is possible to use suitable crushed rock aggregate after petrographical evaluation for construction that in turn may increase the cost.

Best way to avoid AAR is to use innocuous aggregate so that proper performance life of a structure may be assured. However, in the absence of safe aggregate, published literature (Thomas et al., 1997; Afrani and Rogers 1994; Rogers and Hooton 1992; Thomas and Innis, 1998; Thomas 1996; Malver et. al., 2002, 2003; Malver and Lenke, 2005) suggests preventive measures that can be taken in to account when use of potentially reactive aggregate is inevitable. One such measure is use of low alkali cement (alkali content of less than 0.60% Na_2O equivalent; Nevelli, 2000; Rogers et al., 2004). Blast furnace slag cement (Douglas et al., 1992; Rogers et al., 2000) and fly ash (Malvar and Lenke, 2005, 2006; Lenke and Malvar, 2005) have been used effectively to prevent ASR (Donnelly, 1990) in Canada. However, use of slag cement retards strength gain in cold climates (Rogers et al., 2000), like Allai. In Lower Notch Dam (North America) in 1971, use of argillites was permitted with high alkali cement with fly ash as additive and dam performed well for 30 years (Rogers et al., 2000). Another preventive measure is use of chemical admixtures or cement additives such as lithium compounds (Stark, 1992, 1993; Gajda, 1996; Ober, 2002). When lithium compounds (hydroxide, LiOH; lithium nitrate, $LiNO_3$; or lithium carbonate, $LiCO_3$, etc.) are added to cement it forms a lithium bearing gel that greatly reduces potential for expansion. Moreover blended aggregates can be used to minimize the percentage of potentially deleterious rock types (Chaudhry, 2000). Besides these silica fumes and natural pozzolans (such as diatomite, pumicite) can be used to control ASR (Bérubé and Duchesne, 1992; Boddy et al., 2003)

CONCLUSIONS AND RECOMMENDATIONS

The life performance of civil structures mainly depends upon the physical and chemical properties of aggregates. Beside these properties, mineralogy of aggregates controls the extent of ASR. It is imperative that potentially reactive aggregates are identified and appropriately scrutinized prior to construction, as there is no technique to avert the ASR after the concrete has been placed. The main focus of this study was the huge aggregate deposits of Allai-Banan near Banan on Allai river that would be used in the reconstruction of earthquake affected Allai area.

- The Allai aggregates meet engineering properties/parameters/requirements. However, both fine and coarse have ASR potential.
- The reactive constituents, recognized by petrography, are mylonites, slates, phyllites, microcrystalline quartz and highly strained quartz.
- ASTM C 1260, quick mortar bar test shows an expansion of 0.30% at 28 days. This test verifies the conclusion of peterographic test, ASTM C 295.
- It is recommended that the Allai aggregates may be used with low alkali cement, fly ash, slag, microsilica or pozzolana. For this purpose, a concrete mix design should be developed with additives.
- Since the geology of the area is highly heterogeneous, the aggregates of all major tributaries of Allai river should be studied to find out the presence of non deleterious aggregates.
- Innocuous crushed rock aggregate could be blended with Allai gravel to reduce/avert ASR potential.

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