Prospecting of Concrete Aggregates for River Valley Projects : some Specific Problems and Case Studies

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Abstract

A thorough and systematic investigation of construction materials is essential to optimize techno-economic aspects of any major project. The effect on durability and economical feasibility are two major considerations during investigation for finalizing the source of materials. The suitability of an aggregate deposit from all aspects should be assessed by considering geological and other factors during prospecting. Most factors pertaining to suitability of aggregate deposits are related to the geological history of the region. A detailed study including geological origin, size, shape and location of the deposit, thickness and character of overburden, type and condition of rocks, grading, rounding and degree of uniformity of aggregate particles etc. are required to be under taken at the time of prospecting the aggregate. Further studies in laboratory are conducted to assess the suitability of aggregate source for use in concrete. Petrographic and chemical tests are also required for assessing the reactivity and durability of aggregate in concrete.

A systematic approach to include all these studies and to study various parameters for arriving at a judgment regarding suitability with remedial measures etc., if any, is discussed in the paper. Typical case studies of a few important construction materials investigation projects have been brought out to illustrate problems encountered and the remedial measures suggested for effective utilization of available aggregates. Certain chemical constituents of rocks which may cause possible durability problems had been encountered in a few cases and the same have been discussed in the paper.

Introduction

Field Investigation for construction materials prior to construction is confined chiefly to prospecting for aggregate, exploration and sampling of available deposits. However, certain other parameters of natural deposits, which have bearing on the properties of concrete, should also be borne in mind during preliminary investigation. A thorough and systematic investigation of construction materials is very much essential so as to optimize techno-economic aspects of any hydraulic project. The judgment and thoroughness in conducting preliminary field investigations are usually reflected in durability and economy of the completed structure. Every project has unique features and the problems associated with construction materials, may also be unique. Various difficulties faced while exploring these aggregate materials are shape of aggregate, presence of deleterious materials content, selective quarrying, properties of mixed aggregate, and availability of proper materials for wearing surfaces. Therefore, it is necessary to give emphasis on all these aspects and proper investigation techniques to be adopted during prospecting. A few specific and typical case studies of construction materials have been described in this paper to highlight some pertinent problems and methods to over come those technical problems while utilizing the construction materials. Some potential durability problems encountered in these projects have also been presented.

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Prospecting and sampling

When searching for suitable aggregate, it is important to bear in mind that ideal materials are seldom found. Deficiencies or excess of one or more sizes are very common, objectionable rock types, coated and cemented particles or particles of flat shape may occur in excessive amounts. Besides, clay, silt or organic matter may contaminate the deposit or weathering might have seriously reduced the strength of the particles. Therefore, it is important to obtain a reasonable interpretation of the material through proper sampling procedures. Final selection of material may require thorough exploration but all available information on the material should be obtained at the reconnaissance and preliminary exploration stage.

Most factors pertaining to suitability of aggregate deposits are related to the geological history of the region. The geological processes by which a deposit was formed or by which it was subsequently modified are responsible for many of the characteristics that may influence decision as to utilization. The important characteristics to be considered during prospecting are size, shape and location of the deposit, thickness and character of the overburden, types and condition of the rocks; grading, rounding and degree of uniformity of the aggregate particles and ground water level.

The quantity of useful material present at a particular source should also be assessed during prospecting. The depth of deposit may be assessed by drilling exploratory holes in case of rock mass or by digging exploratory pits in case of river born deposits. The percentage of different size fractions available in river born material may be assessed by sieving.

Characteristics of rocks

Geologically the rocks are classified on the basis of their origin, into three main groups viz. Igneous, Sedimentary or Metamorphic rocks. Most igneous rocks are excellent aggregate materials as they are normally hard, tough and dense. Tuffs and certain lavas which have been rendered extremely porous by the inclusion of gas bubbles may be exceptions. These are usually unsuitable for concrete aggregates except in lightweight concrete manufacture because of their low strength, lightweight and high absorption.

The sedimentary rocks range from hard to soft, heavy to light and dense to porous. Sandstone and limestone, when hard and dense, are suitable as aggregate. But sandstones are frequently friable or excessively porous because of imperfect cementation of the constituent grains. Either sandstone or limestone may contain clay, which renders the rock friable, soft, and absorptive; with increased clay content, these rocks grade into sandy or limey shales. Shales are, generally poor aggregate materials, as they are soft, light, weak, and absorptive. Moreover, because they were originally thin bedded, shales are prone to assume flat and slab shapes when reduced to sand and gravel. Conglomerates may not be suitable as aggregate because of the tendency to break down progressively to smaller sizes during handling and processing. Chert and flint are used as aggregate, but have exhibited unsatisfactory service histories. Chert may cause Alkali Aggregate Reaction in concrete.

Characteristics of metamorphic rocks also vary widely. Marble and quartzite are usually massive, dense, and adequately tough and strong. Gneisses are usually very durable and tough but may have the undesirable characteristics of schist. Schistose rocks are thinly laminated and thus tend to assume slab shape; they usually contain large amounts of soft, micaceous minerals and often lack the strength desirable in concrete aggregate. On the other hand, some varieties of schist are suitable as aggregate. Slates characteristically possess a thin lamination, which is undesirable. The summary of some basic properties of rock is given in Table 1.

Laboratory Investigation

Coarse Aggregate

The suitability of a rock type for use as aggregate is established on the basis of various laboratory tests. The representative rock samples, about 50 to 100 kg from each rock type is crushed in laboratory to different sizes for conducting mechanical, chemical and petro-graphic tests. The following mentioned tests are routinely conducted on all aggregate samples for assessing their suitability:

- Specific gravity
- Water absorption
- Soundness (5 cycles)
- Aggregate impact value
- Aggregate crushing value
- Aggregate abrasion value (Los-Angeles)
- Petrographic examination
- Alkali aggregate reactivity test

In addition to these, certain chemical tests to find deleterious constituents such as sulphates, chlorides, alkalis etc. may be required in specific cases. Alkali carbonate reaction test may be required for dolomitic limestones.

Fine Aggregate

Following tests may be conducted on fine aggregate from natural resources:

- Silt and clay content
- Organic impurities
- Specific gravity
- Grading and fineness modulus
- Mortar making properties
- Soundness test and
- Test for mica content may be conducted for specific samples

Table 1: Summary of Engineering Properties of Rocks

Type of rock	Mechanical Strength	Durability	Chemical Stability	Surface Characteristics	Presence of undesirable impurities	Crushed shape
Igneous:						
Granite, syenite, diorite	Good	Good	Good	Good	Possible	Good
Felsite	Good	Good	Questionable	Fair	Possible	Fair
Basalt, diabase, gabbrp	Good	Good	Good	Good	Seldom	Fair
Peridotite	Good	Fair	Questionable	Good	Possible	Good
Sedimentary:						
Limestone, Dolomite	Good	Fair	Good	Good	Possible	Good
Sandstone	Fair	Fair	Good	Good	Seldom	Good
Chert	Good	Poor	Poor	Fair	Likely	Poor
Conglomerate, breccias	Fair	Fair	Good	Good	Seldom	Fair
Shale	Poor	Poor	.....	Good	Possible	Fair to Poor
Metamorphic:						
Gneiss, schist	Good	Good	Good	Good	Seldom	Good to poor
Quartzite	Good	Good	Good	Good	Seldom	
Marble	Fair	Good	Good	Good	Possible	Fair
Serpentinite	Fair	Fair	Good	Fair to Poor	Possible	Good
Amphibolite	Good	Good	Good	Good	Seldom	Fair
Slate	Good	Good	Good	Poor	Seldom	Poor

Suitability

Physical Suitability

As per IS: 383-1970, the aggregate meeting criteria given in Table 2 is suitable for use in concrete. In addition to these, the aggregate should comply with chemical requirement and requirement of shape and size, grading, etc.

Chemical Suitability of Aggregate

Some aggregate materials undergo chemical changes that may be injurious. Such reactions may be of different kinds, including reaction between aggregate material and the constituents of cement, solution of soluble materials, oxidation by weathering and complicated processes that impede the normal hydration of cement. Reaction between certain aggregate materials and the alkalies in cement is associated with expansion, cracking and deterioration of concrete. Small amounts of opal, rhyolites, and certain other rocks and minerals in aggregates (that are otherwise unobjectionable) cause excessive expansion and rapid deterioration. Opal (amorphous, hydrous silica) is the most reactive constituent in aggregates, but the acidic and intermediate volcanic rocks are the most significant because they are most numerous.

In general, aggregates petrographically similar to known reactive types, or which on the basis of service history or laboratory experiment are suspected of reactive tendencies, should be used only with cement that is low in alkalies. Such reactions are reduced in intensity and probably eliminated in some instances, by the limitation of the alklies (Na_2O plus 0.658 K_2O) to not more than 0.6 percent of the cement and/or the use of an effective pozzolan. Zeolites and montmorillonite-type clay minerals can augment the supply of alkalies by cation exchange reactions. A reaction, similar in effect to that just prescribed, is the alkali-carbonate reaction that occurs when certain dolomitic limestones are used as coarse aggregate in conjunction with high-alkali cement.

If the aggregates proposed to be used in the project construction are found to be reactive, then the following remedial measures need to be adopted to control alkali-aggregate reaction in concrete.

(i) Use of pozzolanic material such as fly ash by replacing cement up to a minimum of 25% by weight of cement or silica fume upto 15% by weight of cement.

(ii) Use of Portland slag cement (PSC) with slag content as follows:

- When alkali content is upto 0.9%, use slag content more than 50%.
- When alkali content is more than 0.9% but less than 2.0%, use slag content more than 65%.

The extremely fine fractions of aggregate materials are commonly classed as silt or silt and clay and should not be permitted in large amounts because of their tendency to increase water requirements of a mix and thus contribute to unsoundness or to decreased strength or durability. Montmorillonite-type clays which constitute a part of the sand particles have produced

Table 2: Physical Suitability of Aggregate

S. No.	Property	Requirement	
		Wearing surfaces	Non-wearing surfaces
1.	Specific gravity (General range)	2.5 – 2.8	2.5 – 2.8
2.	Water absorption, % Max.	1	1
3.	Aggregate impact value, % Max.	30	45
4.	Aggregate crushing value, % Max.	30	45
5.	Aggregate abrasion value, % Max.	30	50
6.	Soundness (5 cycles in Na_2SO_4), % Max.	12	12

detrimental effects by causing excessive loss in slump. Mica is a common contaminating substance in aggregates and is undesirable because of its soft, laminated and absorptive character and susceptibility to disintegration along cleavage planes contribute to reduced strength and durability.

Some pertinent problems

Aggregate for Wearing Surfaces

Some rock types are very strong from geological consideration as well as in terms of their mechanical properties given by aggregate impact value and aggregate crushing value but are very poor in abrasion value when tested for Los-Angeles abrasion value. This phenomenon is commonly encountered in Himalayan region. Himalayas are the youngest mountain ranges and mostly comprise of metamorphic formations. Mica is present in abundance in these rocks. As such, most rock types found in this region are poor in abrasion value. Due to poor abrasion value, most rocks cannot be used for wearing surfaces in concrete as per the criteria given in Table 2. Only some good quality quartzite rocks and other similar formations were found to satisfy the abrasion criteria. Due to non-availability of rocks with abrasion loss within 30% as specified in IS: 383-1970, the aggregate is sometimes transported from long distances, which costs heavily on the project cost. Many times, all concrete for wearing and non-wearing surfaces is not segregated and therefore whole of the aggregate is required to follow the criteria for wearing surfaces.

Under these circumstances, it is recommended to clearly segregate the concrete for wearing and non-wearing surfaces so that the local aggregate can be utilized for non-wearing surfaces and only limited aggregate is required to be transported for wearing surfaces. There is also scope to consider utilizing locally available poor abrasion value aggregate for wearing surfaces by adding microsilica in concrete. It is reported that the use of microsilica improves the abrasion resistance of concrete and can compensate to some extent the poor abrasion value of aggregate. However, the exact contribution of microsilica in enhancing the abrasion resistance of concrete needs to be further studied.

Quality of Crushed Aggregate

When the bedding planes and joints in rocks are weak and closely spaced, the crushing of these rocks yields flaky and elongated aggregate despite their good mechanical properties. Flaky and elongated aggregate results in poor workability of concrete and causes high paste requirement. Such defective aggregate content should not be more than 15% for making a good quality concrete. Apart from nature of rocks, crushed aggregate is also influenced by crushing method adopted. The crushing ability of rocks should be taken note of during investigation itself to assess its nature to yield flaky materials.

Selective Quarrying

Sometimes, the aggregate formations are frequently varying in close vicinity and some bands of aggregate are suitable from mechanical properties point of view while others are not suitable. Under these circumstances, selective quarrying needs to be resorted to if any other exclusive source is not available. However, it is very difficult to carry out selective quarrying when the construction work is in progress. There is always a risk of intermixing of aggregate. Therefore, the properties of mixed aggregate in different proportions should be established and clear guidelines for selective quarrying should be brought out based on properties of mixed aggregate. If the unsuitability of some bands is due to chemical properties, then selective quarrying should be recommended with extra caution. The over burden, stability of strata during quarrying, forest cover loss etc. should be given due consideration during prospecting.

If the presence of contaminants such as silt and clay, dry wood in the quarrying location is observed, the necessary treatment such as washing of aggregate etc. should be recommended. Any other precautions to be adopted such as remedial measures against Alkali Silica Reaction should also be clearly mentioned in recommendations.

Case studies

Tala Hydroelectric Project

Tala Hydroelectric Project is a run of the river scheme, located 3 Km downstream of the existing 336 MW Chukha Hydroelectric Project on river Wangchu in South West Bhutan in Eastern Himalayas. The project envisages construction of a 92 m high concrete gravity dam; three desilting chambers each of 250 m x 13.90 m x 18.5 m size for removal of suspended sediments of 0.2 mm and above size coming with the river water diverted through the intake structure; a modified horse shoe tunnel of 6.8 m diameter and 23 Km in length to carry the water to underground powerhouse (206 m x 20 m x 44.5 m) for utilizing a gross fall of 861.5 m. A tailrace tunnel of 3.1 Km length and 7.75 m diameter will discharge the water back into river Wangchu. The installation capacity of powerhouse is 1020 MW (6 x 170 MW).

Mechanical Properties of Aggregate

Construction materials investigation at pre-construction stage was taken up by CSMRS. A total of 24 quarries spread in the vicinity of different components of the project were identified. The laboratory investigation revealed that the Los-angeles abrasion value of all quarries was very high rendering most of the samples suitable for non-wearing surfaces only and a few even unsuitable for use in concrete.

Total 63 samples from above mentioned 24 quarries were tested. There were 10 such quarries for which, some samples were found suitable for both wearing as well as non-wearing surfaces while remaining were found suitable only for non-wearing surfaces. In such cases, selective quarrying was recommended. During actual application, it is found that selective quarrying was not practically feasible and all these quarries were either abandoned or used only for non-wearing surfaces.

For wearing surfaces, material from a distant Torsa RBM was used. Torsa RBM consisted of mainly quartzite rock, having abrasion value less than 30% and was transported from 60 to 80 Km at different work sites for use in wearing surfaces.

Alkali-Silica Reaction (ASR)

The samples from quarries found suitable in mechanical tests, were subjected to Petrographic analysis. The results of Petrographic examination are summarized in Table 3. It is seen that the strained quartz content with the angle of undulatory extinction more than 15^0 is very high (more than permissible limit of 20%). As such, the aggregate from the quarries was found susceptible to alkali aggregate reaction. The potential reactivity of aggregate was further confirmed by conducting accelerated mortar bar test. Alkali aggregate reactivity in case of six quarries having expansion more than 0.1% as given in Table 3 was confirmed by mortar bar test. Therefore, further tests with the type of cement actually used were suggested and the aggregate was recommended to be used with remedial measures against ASR. PSC with not less than 50% slag content was found very effective remedial measure against ASR and the same was used in dam construction and HRT lining with such reactive aggregate.

Mahanadi-Godavari Link Canal Project

Mahanadi-Godavari Link Canal Project envisages the construction of 420 Km long lined canal for carrying a discharge of 425 cumecs in the A.P. Portion. The proposed bed width of the canal is 37 m with a full supply depth of 7 m. The link canal shall have a number of cross drainage works on the canal alignment.

For construction materials investigation work, a total of 17 rock samples from 16 prospective quarries for coarse aggregate and 10 sand samples from 7 river bed deposits for fine aggregate were collected. Based on the physical test results, 11 quarries for coarse aggregate were found suitable for both wearing as well as non-wearing surfaces whereas 5 quarries were suitable for non-wearing surfaces only. The Petrographic analysis conducted on four randomly selected quarries revealed that strained quartz or any conventional reactive mineral was not present in deleterious proportion in any of the tested sample. Hence the coarse aggregate samples were not susceptible to alkali-silica reaction and were found suitable in all respects for use in concrete.

Out of 10 sand samples collected from 7 river deposits, samples from 4 river bed deposits were subjected to Petrographic analysis. The Petrographic examination revealed that the sand did not contain strained quartz in deleterious proportions but they contained the ferruginous grains in varying amount from 30 to 75% in different samples. The presence of ferruginous grains may affect the concrete strength and may cause durability problem in the same way as clay minerals. As such, it was found necessary to assess the suitability of sand by conducting strength and durability test before using the sand from the identified deposits in concrete.

Lower Goi Dam Project, M.P.

Lower Goi Dam project is proposed to be constructed on river Goi, a tributary of river Narmada in Barwani District of Madhya Pradesh. It comprises of a 42 m high, 2220 m long earthen dam and 176 m long concrete ogee shaped spillway with 10 radial gates.

For construction materials investigation, 7 rock samples from 3 prospective rock quarries and one riverbed material were collected and tested in the laboratory. In addition, three natural sand samples from 2 riverbed deposits were also collected for fine aggregate requirement. The available rock quarries were identified as basalt consisting of mainly plagioclase, pyroxene, iron oxide and altered glassy materials and volcanic glass. Based on mechanical parameters, all

Table 3: Results of Petrographic Examination and Mortar Bar Tests of some Potential Rock quarries

S. No.	Name of Quarry	Quartz Content, %	Strained Quartz Content, %	Undulose Extinction Angle of Quartz, degrees	Accelerated Mortar Bar Expansion, %
1.	Honka Nallah	78-80	96	32-35	0.078
2.	Dam site Road	3-5	74	26-28	0.033
3.	Lobhichu	96-98	96	25-27	0.048
4.	Bunakha	85-87	85	38-40	0.093
5.	Padechu	97-98	99	28-32	0.091
6.	Geduchu	94-96	98	40-42	0.093
7.	Mirchingchu	90-92	98	25-26	0.159
8.	Surgeshaft Top Portal	40-43	96	34-38	0.308
9.	Surgeshaft Lower Portal	88-92	96	26-28	0.274
10.	Intermediate Adit	67-71	98	34-36	0.153
11.	Main Access Tunnel	79-83	98	35-38	0.165
12.	TRT	96-98	97	25-28	0.065
13.	Monitar	96-98	96	25-27	0.101
14.	Tabji Nallah	85-87	85	38-40	0.074
15.	Torsa RBM (L/B)	84-88	72	-	-

the rock samples were found suitable for use in concrete for wearing as well as non-wearing surfaces as per IS: 383-1970. However, the presence of volcanic glass (5 to 15%) and altered glassy materials (1 to 15%) in different basalt quarries, revealed from Petrographic analysis, could be harmful from alkali-aggregate reactivity point of view. As such, the rock samples were tested for alkali-aggregate reactivity by accelerated mortar bar method and the mortar bar expansion more than the acceptable maximum limit of 0.1% at 22 days was obtained in four of the total 7 samples tested. Therefore, the potential reactivity of aggregate with alkali was confirmed and the aggregate was recommended for use in concrete with preventive measures against alkali-silica reactivity as suggested under para 5.2.

For fine aggregate, samples from 2 river bed deposits were found suitable with respect to physical properties but the Petrographic analysis revealed the presence of ferruginous (2 to 10%) and calcareous grains (2 to 15%) which may cause expansive deleterious reaction if used in concrete. The accelerated mortar bar test conducted on three samples revealed that the expansion is more than 0.1% at 22 days in case of two samples showing the potential reactivity of fine aggregate with cement alkalis and as such it was recommended to use these materials with some preventive measures.

Conclusions

Based on CSMRS experience of construction materials investigations for a variety of major projects and specific parameters mentioned in the present paper, the following conclusions are drawn:

- Amongst various types of natural deposits, the sand and gravel materials from stream deposits are most economical and durable source of aggregate. However, the presence of contaminants in excess quantity in these deposits may require necessary treatment before using.
- Attention must be directed to the possibility of zones or layers of undesirable materials in the rock mass during prospecting and as such selective quarrying from every desirable zone in a deposit should be recommended.
- Practical difficulties likely to be faced during exploitation of a particular source should be given due consideration such as intermixing of different aggregate types during quarrying, shape of crushed aggregate, presence of contaminants etc.
- The necessity of selective quarrying, excessive washing or special processing required should be assessed and recommended accordingly for utilization of a particular source.
- Presence of ferruginous and calcareous grains in aggregate may cause durability problems and need to be further studied for their long-term effect in concrete.
- Physical and chemical suitability of each collected sample should be assessed in laboratory and the recommendation must reflect remedial measures required in case of any deficiency.

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