Study on suitability of basalt artificial aggregate in Cambodia

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Abstract. Aggregate property directly affects concrete property. When natural aggregate sources are lacking, artificial aggregates should be considered. The strata in Cambodia are dominated by sedimentary rocks with weaker lithology, which are not suitable for artificial aggregate. The quality of gneiss and limestone is good, but the distribution area is small, so it is not suitable for mass mining. Basalt is widely distributed, and the rock strength is generally high. There are problems such as scattered distribution, poor uniformity, and large property changes. Suitability of basalt artificial aggregate is studied in combination with specific projects. Research works are from outside to inside, from shallower to deeper. Through general survey and primary selection of quarry, surveying and sampling, rock mineral identification and chemical composition analysis, rock physical mechanics test, alkali activity test and aggregate processing property and other analysis tests, its quality indicators and reserves are found out. Studies have shown that quality and reserves of aggregates in the survey yard can meet the needs of the project, mining and transportation are convenient, making it an ideal choice for concrete artificial aggregates. Research methods and results can be used as the reference for similar projects.

1. Preface
In hydraulic mass concrete, the proportion of aggregate is as high as about 85%, aggregate performance directly affects concrete performance[1]. Some rivers have deep sand and gravel layers and can be used nearby as needed. Some projects lack natural aggregate sources, artificial aggregates rolled by natural rocks can be considered. High-performance artificial aggregate is a premise to ensure the strength, durability and crack resistance of concrete, and the suitability of artificial aggregate must be fully demonstrated.

There are many successful cases of artificial aggregate selection in large-scale water conservancy and hydropower projects at home and abroad. The concrete artificial aggregate of Wudongde Hydropower Station was rolled with excavation material of underground cavern at dam site and stone material at quarry. Lithology of the stone is mainly limestone and dolomite[2]. Mixed gneiss and marble were used as concrete aggregates in Magi Hydropower Station of Nujiang river. Granite aggregates were used in Three Gorges and Dagangshan hydropower stations. Mostly common limestone aggregates were used in Shatuo, Guanyinyin, and Goupitan hydropower projects. Combination of metamorphic sandstone coarse aggregates and marble fine aggregates was used in Jinping I Hydropower Station[3]. In Xiluodu Hydropower Station, basalt was adopted to make coarse aggregate and limestone to make fine aggregate[4]. Granite gneiss was used as artificial aggregate in a large hydropower station in southeast Asia[5]. Quartz sandstone was used to roll artificial aggregate in Elsay Hydropower Station in Cambodia. In summary, most igneous rocks are fine aggregates, and metamorphic rock artificial aggregates are common. Sedimentary rocks have different properties, and some can be used as aggregates.
Cambodia is located in south-central part of Indochina Peninsula, bordering with Thailand, Laos, and Vietnam. Strata are relatively well exposed, Mesozoic and Cenozoic were mostly developed, while Upper and lower Paleozoic and Precambrian are not only less exposed, but also scattered[6]. Most of strata and lithology is sedimentary rock, a small part is limestone and gneiss. In eastern part, "Plateau Basalt" composed of basalt, alkaline basalt and aluminum basalt has thickness of 100-140m and age value of 2.6-1.77Ma. A plateau basalt eruption occurred in the Middle-upper Pleistocene epoch of Quaternary, mainly alkaline olivine basalt, with time limit of about 65,000 years, mainly distributed in the north-central part (shown in Figure 1).

![Basalt distribution map of Cambodia.](image)

Although sedimentary rocks are widely distributed, most of them are relatively soft with great lithofacies changes and not suitable for aggregates. Gneiss and limestone have good quality and small distribution area. Basalt was formed from Neogene to Quaternary which is widely distributed and irregular. It is overflow facies basic effusion rock, exposed in shallow surface or buried in underground. It is Mostly gray-black, sometimes gray-green, dark purple, etc. It is commonly shown as variegated texture, stomata and almond structure. The thickness of the strata varies greatly. It is thick near crater, shown as thick-layered and shallow weathering. Edge of rock mass is severely broken and weathering and thin to several meters, underlying by Quaternary overburden.

Basalt artificial aggregate has been used in some projects in Cambodia, mostly used for channel surface concrete lining, dams, bridges and culverts, etc. The concrete amount is not large, and no quality problems have been found. Due to the limitation of the site conditions, comprehensive and system analysis and testing works have not been carried out before. Basalts are formed late in Cambodia. Rock strength is generally high, but uniformity is poor and properties change greatly. It is easy to cause some problems such as instability of aggregate properties to affect concrete strength and durability, and yard reserves cannot meet project needs. It is necessary to carry out research on suitability of basalt artificial aggregates in specific projects.

2. Surveying material yard selection

The Reaksa Reservoir in Preah Vihear province in Cambodia is located at middle and upper reaches of the Sen River. Dam type is a mixed dam, consisting of earth dam sections and concrete dam section. Maximum dam height is 22m, with total storage capacity of 256.9 million m³. It is a large (2) reservoir belongs to class II project. The project location is shown in Figure 1. Concrete volume is 420,000 m³, which requires 200,000m³ coarse aggregate and 120,000m³ sand. There is no suitable natural sand and gravel material in the river, artificial aggregate is required.
Basing on full study of geological data of region and reservoir area, strata and lithology distributed in the region near the dam site was surveyed and studied according to general survey accuracy, and location of material yard is initially determined. Cretaceous argillaceous siltstone and sandy conglomerate are widely distributed in the project area, with soft lithology and deep weathering, which does not meet the requirements of original rock. Basalt is distributed in the slope on left bank near the dam site. Terrain is complete and gentle. Overburden is thin and bedrock is shown as thick-layer shape. Hammering sound of boulder surface is crisp and weathering is shallow. No large fractures have been found to pass through, and structure is simple. Basalt can meet original rock requirement for artificial aggregate by preliminary judgment, and can be used as primary surveying material yard.

According to relevant specifications, the quarry is classified as Class I quarry, and interval between exploration points should be 100-200m during detailed investigation stage. Total 5 drilling holes were arranged in the field with interval of 100m~150m. The north is a gully, bedrock is exposed, and no drilling was arranged. Taking into account factors such as economic feature of underground excavation in material site, single hole depth is controlled within 15m, drilling layout is shown in Figure 2. Lithology of the strata exposed by drillings: overburden is Quaternary eluvium and slope wash with thickness of about 0~1.50m. Bedrock is basalt and volcanic breccia, thickness of strongly weathered rock is 0.2~0.3m, thickness of weak weathered rock is 0.6~1.50m. Core samples were taken for inspection according to drilling and lithology. Rock and soil stratification of the field is listed in Table 1.

Table 1. List for rock and soil stratification of drillings in the quarry.

| Drilling No | overburden (m) | elevation (m) | basalt (m) | volcanic breccia (m) |
|-------------|----------------|---------------|------------|---------------------|
| ZK221       | 0.0-0.50       | 0.5-12.6      | 71.1-70.6  | 12.6-15.0           |
|             | 71.1-70.6      | 70.6-58.5     | 58.5-56.1  |                     |
| ZK222       | 0.0-1.50       | 1.50-13.40    | 66.5-65.0  | 13.4-15.7           |
|             | 66.5-65.0      | 65.0-53.1     | 53.1-50.8  |                     |
| ZK223       | 0.0-0.80       | 0.80-2.00     | 72.8-72.0  | 13.4-14.2           |
|             | 72.8-72.0      | 70.8-59.4     | 72.0-70.8  | 59.4-58.6           |
| ZK224       | 0.0-0.40       | 4.50-15.00    | 72.9-72.5  | 0.40-4.50           |
|             | 72.9-72.5      | 68.4-57.9     | 72.5-68.4  |                     |
| ZK225       | 0.0-0.40       | 0.40-12.00    | 71.1-70.7  | 12.0-14.4           |
|             | 71.1-70.7      | 70.7-59.1     | 59.1-56.7  |                     |
3. Rock test research

Artificial aggregate basic characteristics directly affect compounded concrete performance. For hydraulic mass concrete, the most important properties of artificial aggregate are strength properties, durability and thermodynamic properties[7].

According to the correlation between rock test specifications and indicators, selected test items are rock and mineral identification, chemical composition analysis, rock physical mechanics test, alkali activity test and aggregate processing performance test[8].

3.1. Rock and mineral identification and chemical composition analysis

The rock is gray-green, massive, composed of phenocrysts and matrix. The phenocrysts are plagioclase, with content of about 5-10%, shown as lath shape, partly chlorite. The matrix is plagioclase, pyroxene, magnetite, etc. The matrix has an intergranular structure, and a large number of plagioclase lath-like crystallites are arranged in disorder, forming angular pores, containing several small particles of pyroxene and magnetite. Rock chemical composition is mainly SiO₂, Al₂O₃, Fe₂O₃+FeO, CaO, MgO, and content of Na₂O and K₂O is slightly less.

3.2. Experimental research on original rock

Original rock physical and mechanical tests include dry density, saturated compressive strength, water absorption and alkali activity tests.

Eight groups of lightly weathered to fresh core samples from stockyard drillings were adopted to conduct indoor physical and mechanical tests. Test results are shown in Table 2. It can be seen from the table, basalt: block dry density is 2.67~2.69g/cm³, which meets the requirements of natural building materials survey specification( needs to more than 2.4g/cm³). Saturated compressive strength is 40.8~101.2MPa, which belongs to relatively hard rock to hard rock, and meets the Saturated compressive strength specification requirements(needs to more than 40MPa). Water absorption rate is 0.09~0.92%, meeting the specification requirements (needs to not more than 2.5%). Volcanic breccia: saturated compressive strength is 16.1-73.3MPa, most of which are softer to harder rocks, with large differences in strength. water absorption rate is 0.21 to 4.60%, and some cannot meet the specification requirements. Volcanic breccia should be treated as useless layer.

Aggregate reaction is one of the important reasons for concrete durability damage. Once such damage occurs, the concrete will produce integral damage and cannot be remedied. Reason for the failure is due to chemical reaction between active ingredients in aggregate and cement, which causes concrete volume expansion and self-stress inside concrete. Self-stress exceed its bearing capacity and cause failure[9].

M.Korkanc etc. [10] studied eleven types of basalts in Nied region of Turkey, indicated that basalts containing neutral acid or volcanic glass in matrix have potential alkali activity. Among experiments with different composition and structural types of basalt aggregates, Li Zhen etc. [11] found that basalt aggregates containing minerals such as chalcedony and microcrystalline quartz have potential alkali activity. Aggregate alkali activity test can use petrographic method, chemical method, mortar rod rapid method, rock cylinder method, concrete prism method and other methods. Aggregates of this project are tested by mortar rod rapid method. 14d expansion rate of the mortar specimens is 0.074%, which is less than the criterion of 0.1%. It belongs to non-alkali active aggregate.

Table 2. Statistical table of strength test results of core samples in the quarry.

| Drilling No | Lithology          | Dry density (g/m³) | Saturated compressive strength (MPa) | Water absorption (%) | Quality Evaluation         |
|-------------|--------------------|--------------------|--------------------------------------|----------------------|-----------------------------|
| ZK221       | Basalt             | 2.68               | 40.8-87.5                            | 0.09-0.32            | Meet the requirements       |
| ZK222       | Basalt             | 2.68               | 69.5-78.9                            | 0.19-0.34            | Meet the requirements       |
| ZK223       | Basalt             | 2.67               | 59.5-98.9                            | 0.06-0.92            | Meet the requirements       |
| ZK221       | Volcanic breccia   | /                  | 21.1-58.6                            | 1.82-3.45            | Some can’t meet the requirements |
| ZK222       | Volcanic breccia   | /                  | 68.7-73.3                            | 0.48-0.97            | Meet the requirements       |
| ZK223       | Basalt             | 2.68               | 47.1-92.1                            | 0.20-0.78            | Meet the requirements       |
3.3. Aggregate processing performance test

Three groups of rock samples are taken from the useful stratum of basalt in the stockyard for aggregate processing performance test. Processing rate of coarse aggregate is 86%. Coarse aggregate performance index: saturated surface dry water absorption rate is 0.6% ~ 0.8%, which meets the index requirement of the specification (not more than 2.5%). Apparent density is 2860 kg/m³, which meets the specification index requirement (not less than 2550 kg/m³). Mud content is 0.1% ~ 0.4%, which meets the specification requirements of D20 and D40 particle size class (not more than 1%). Content of needle flake particles is 3.7% to 7.5%, which meets the quality requirements of the specification (less than 1.5%). Poorly shaped particles are mainly flakes, crushing value is 3.9%, which meets the quality requirement of the specification (not more than 20%). Soundness of crushed stone is 3.6%, which meets the quality index property of concrete without antifreeze requirements (not more than 12%). Content of weak particles is 4.1%, which meets the quality requirement of the specification (less than 5%). Content of sulfide and sulfate is 0.2%, which meets the quality requirement of the specification (less than 1%). Organic content is lighter than standard color.

Processing yield of basalt fine aggregate (sand) is 92%, its gradation is in the range of medium sand to coarse sand. Performance test indicators of fine aggregate: fineness modulus is 2.43 ~ 3.45, stone powder content is 8.3% ~ 9.8%, apparent density is 2860 kg/m³, sulfide and sulfate content is 0.3%, soundness is 3.8%. Gradation test shows that content of particles larger than 1.25mm is relatively high, while content of particles ranging from 0.16mm to 1.25mm is relatively low. All properties meet the requirements of relevant specifications, and the gradation can be adjusted and improved through later production performance test of sand and gravel aggregates.

4. Reserve analysis and calculation

Based on topographic and geological conditions, survey levels, and layout of exploration points, average thickness method, parallel section method, triangle method and other methods can be adopted for reserves calculation [12]. Terrain of the site is relatively flat. Exposed rock distribution in each drilling was relatively stable, and minable thickness is basically close, so average thickness method is adopted. Overburden, strongly weathered layer and volcanic breccia should be removed as useless layers. Thickness of useless layer, minable thickness and stripping ratio of each borehole is shown on Table 3.

| Drilling No | Minable depth (m) | Thickness of useless layer (m) | Minable thickness (m) | Stripping ratio (%) |
|-------------|-------------------|--------------------------------|----------------------|---------------------|
| ZK221       | 12.6              | 0.8                            | 11.8                 | 6.8                 |
| ZK222       | 13.4              | 1.8                            | 11.6                 | 15.5                |
| ZK223       | 13.4              | 2.0                            | 11.4                 | 17.5                |
| ZK224       | 15.0              | 4.5                            | 10.5                 | 42.9                |
| ZK225       | 12.0              | 0.4                            | 11.6                 | 3.4                 |

The above table shows that mineable thickness exposed by each drilling in the site is generally more than 10m, and stripping ratio is mostly below 20%. The mining economic property is better. But in some areas (near ZK224) the stripping ratio is above 40%, economic property is poor, it is recommended to avoid this area as much as possible.

Calculated reserves based on the site area of 60,000 m² are above 600,000 m³. Taking into account the poor mining economic property in some sections, actual mineable area is about 50,000 m². Preliminary estimate of the mineable volume is about 500,000 m³, reaching 1.5 times the design requirement, which can basically meet the needs of the project.
The survey material yard is a low hill, which can be mainly ground mining combined with underground mining, which is easier to excavate. Transportation distance is 3.5km, and the nearest road is 500m away. The transportation is convenient and economic benefits are significant.

5. Conclusion
(1) Most of strata and lithology in Cambodia are not suitable for artificial aggregate. Basalt is widely distributed and rock strength is generally high, but it has problems of scattered distribution, poor uniformity, and large changes in properties. This article takes the project as an example to carry out study on suitability of basalt artificial aggregates. Research methods can provide a reference for similar projects.

(2) The research shows that: Rock thickness of the survey material yard is large, and useless layer is thin. Quality indicators such as rock minerals and chemical composition, physical and mechanical properties, alkali activity, and aggregate processing performance meet the requirements of dam concrete. With abundant reserves, convenient mining and transportation, and significant economic benefits, it is an ideal choice for concrete artificial aggregates. The research results can provide references for similar projects.

(3) Formation age of basalt in Cambodia is late, and rock thickness and properties of different parts are quite different. It should be cautious during stockyard surveying and selection, it must not be simply judged by experience. Only by carefully investigating and demonstrating in accordance with the specifications, then proper and actual conclusions can be drawn.

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