UNCOMPACTED VOID CONTENT VERSUS MAXIMUM PARTICLE SIZE FOR ROCKFILL MATERIALS

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Abstract:
Rockfill Materials are important one as they are used to construct structures like dams, embankments etc. The materials cannot be tested directly due to their large size. The sizes are modeled down to reduce the sizes for testing in the laboratory. The shear strength parameters are very much dependent on particle sizes and angularity, surface texture, grading, shape. Unconfined void content (UVC) represents angularity, surface texture, grading and shape for fine aggregates. The same concept has been used for rockfill materials by testing for UVC. The UVC have been determined for alluvial and quarried rockfill materials. For each material, three modeled grain size distribution curves (for 19mm, 9.5mm & 4.75mm) are obtained for testing them in the laboratory for UVC. The UVCs are plotted versus maximum particle sizes. The UVC observed to be decreasing linearly on semi-log plot with maximum particle sizes. The UVC can be extrapolated using the relation obtained for bigger sizes.

Keywords: Rockfill materials; uncompacted void content; maximum particle sizes.

1. Introduction
Rockfill dams are constructed using mostly rockfill materials obtained from quarries. The quarried materials are obtained by blasting the parent rocks and consist of angular to subangular particles. In northern India, many of the rockfill dams are being constructed with alluvial materials. These materials are found in large quantities in the riverbeds of the tributaries of the major rivers Ganges and Indus. These rivers have the origin in the Himalayas and the source of water in them is primarily due to melting of snow. These rivers carry rock fragments produced by glaciation and weathering. The impact, rolling and sliding of the rock fragments in the riverbed produce rounded/ subrounded particles. The two rockfill dams viz. Tehri dam (260.5m) and Ranjit Sagar dam (160m) in India are of alluvial materials.

Rockfill materials consist of particles of large size. Testing and understanding the behaviour of the rockfill materials have been a challenging task to geotechnical engineers. Some kind of modeling technique is often used to reduce the size of particles so that the samples prepared with smaller size particles can be tested. The material parameters obtained from the tests are generally used to get the parameters for large size prototype material by extrapolation.

The shape, surface texture and grading of the particles are known to affect the shear strength of the granular materials. These characteristics of the material are expressed by a single property known as uncompacted void content (UVC) for fine aggregate. For rockfill materials also the UVC is being used as an index property based on which the real stress strain behaviour can be predicted. It is also learnt that the UVC varies with maximum particle size of the materials. In the following study a relationship between UVC and maximum particle size is proposed for various rockfill materials collected from different project sites.

2. Background
The behaviour of rockfill materials is often studied by performing triaxial tests on modeled rockfill materials because actual rockfill material is large in size. Four modeling techniques are available to model the rockfill material for laboratory testing. The first modeling technique called scalping technique (Zeller and Wullimann 1957) involves a series of grain size distribution curves to be prepared by successively sieving out the coarsest of the fractions from the preceding sample. The maximum particle size of rockfill material after scalping that could be tested in the laboratory is then chosen such that its size is less than 1/5 or 1/6 of the diameter of the test specimen. In the second method namely, parallel gradation technique (Lowe 1964), an average prototype gradation curve is prepared. A curve parallel to this curve is drawn keeping the maximum size of the particles...
within the ratio of 1/5 to 1/6 of the diameter of the specimen that can be accommodated in the testing equipments. Gupta and Ramamurthy (1978) presented theoretical justification for modeling the rockfill materials for testing by parallel gradation technique particularly for rigid round particles. The third method is by Fumagalli (1969). He used the quadratic grain size distribution curve of the testing material based on the maximum size permissible in the test equipment. The fourth method is known as Replacement Technique (Frost 1973). In this method, the tests are carried out by replacing the oversize fractions by an amount of relatively finer but still coarse fractions on the basis that the latter will have the same weight, the same cross sectional area, the same surface or the same volume. In addition, some researchers have also indicated that the state of compactness has a marked influence over the mechanical characteristics of rockfill materials. Fumagalli (1969) used the void ratio and Becker (1972) resorted to use of relative density. Charles (1973) used identical unit weights for laboratory samples and for the material of the prototype. Out of all the above modeling techniques, parallel gradation technique is considered to be more appropriate and as such it is widely used (Ramamurthy and Gupta 1986).

Leslie (1963) presented the data for five soils all having a uniformity coefficient of 3.3, but having different average particle sizes. For a given compactive effort, these sands achieve different void ratios. However, the angle of internal friction was much the same for each sand. The effect of the greater initial interlocking in the sand with the largest particles is compensated by the greater degree of grain crushing and fracturing that occurs with the large particles because of the greater force per contact.

Over the years several tests have been evolved for measuring coarse aggregate quality in terms of particle shape, angularity and surface texture. Standardized tests include percentage of fractured particles (ASTM D5821-1995), flat and/or elongated particles in coarse aggregate (ASTM D 4791-1999), and index of aggregate particle shape and texture (ASTM D 3398-2000). Ahlrich (1996) proposed an uncompacted voids test for coarse aggregate (Fig. 1) that is similar to the uncompacted voids test for fine aggregate (ASTM C 1252-1998).

Hossain et al. (2000) used this apparatus to determine the uncompacted void content of coarse aggregate used in asphalt concrete for road pavements. This test was intended to quantitatively express shape, angularity and surface texture of the particles. He used this test apparatus for three size ranges of the particles of coarse aggregate as 12.5-19.0 mm, 9.5-12.5 mm and 4.75-9.5 mm. The method prescribed by ASTM C 1252 (1998) was adopted.

Fig. 1: Line Diagram of UVC Apparatus

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Fractured and flat and/or elongated particle tests are subjective tests. Particle index and uncompacted voids are quantitative tests and include the effect of particle surface texture. Fractured and flat and/or elongated particle tests are more time consuming and labour intensive compared to the uncompacted voids and particle index tests. The uncompacted voids test for coarse aggregate is more objective and less labour intensive and time consuming (Hossain et al. 2000).

3. Rockfill Materials

For the present research work seven river valley projects in India have been selected. The locations of the projects selected are shown in Fig. 2. Seven alluvial and three quarried rockfill materials have been chosen for the study. A brief description of the location and mineralogy of materials is listed in Tables 1 and 2.

4. Methodology and Experimental Investigations

Ahlrich (1996) proposed an apparatus to determine UVC for coarse aggregates up to 19 mm maximum particle size. To determine UVC for bigger sizes e.g. 25mm, 50mm and 80mm (for which, in general, drained triaxial test are performed), relations are sought between them for different rockfill materials. Using these relations the UVC can be extrapolated for bigger sizes. For this, three modeled rockfill materials of 19.00, 9.50 and 4.75 mm maximum particle sizes have been obtained by parallel gradation technique for the materials obtained from all the project sites. A typical grain size distribution curve for various maximum particle sizes of rockfill material obtained from Purulia dam site is presented in Fig. 3. Then these modeled rockfill materials are tested for UVC.

4.1. The Apparatus

The apparatus consists of two cylinders. The bottom cylinder called cylindrical measure, which is one side open, has internal dimension as 154 mm height and 152 mm diameter. The upper cylinder which functions as a funnel is of 152 mm internal diameter and fitted with a conical cylinder of height 44 mm and 101 mm smaller diameter at the bottom end. The opening at the bottom is provided with a lid which can be opened suddenly to pour the material in the cylindrical measure. The bottom of the upper cylinder is fixed at a clear height of 114 mm from top of the cylindrical measure. The test apparatus is fabricated in the laboratory as proposed by Ahlrich (1996). The description of the apparatus is given in the subsequent article. The photograph of the apparatus is shown in Fig. 4.

4.2. The Procedure

The upper cylinder is filled freely with 5 kg of modeled rockfill material after striking off the excess materials. The bottom lid is then suddenly opened and the material is allowed to freely fall in the cylindrical measure. Extra material, if any, is strike off to level the surface. Then the material collected in the measuring cylinder is weighed. If the cylindrical measure is not completely filled with the material then the surface of the material is leveled and the volume of the material is calculated by measuring the height of the unfilled portion of the cylindrical measure. The UVC is then calculated using following equation:

\[ UVC = \left( \frac{V - F}{V} \times 100 \right) \]

where, 
- \( V \) = Volume of the material collected in the cylindrical measure in ml,
- \( F \) = Net weight of the material collected in cylindrical measure in gm,
- \( G \) = Bulk dry specific gravity

5. Result and Discussion

The values of UVC have been plotted with maximum particle size on semi-log scale for the rockfill materials. Plots have been shown in Figs. 5 & 6 for the alluvial and quarried rockfill materials. Interestingly, it is noted that on semi-log plot, the relationship between UVC and the maximum particle size is linear (in general) for all the rockfill materials. Therefore, UVC not only measures shape and surface texture of the particles, but it also includes the effect of gradation and the maximum particle size. For bigger maximum particle sizes, UVC can be obtained by extrapolation.
<table>
<thead>
<tr>
<th>S. No.</th>
<th>Project Name</th>
<th>Location</th>
<th>Name of the Rocks</th>
<th>Structure/ Texture/ Colour and Mineralogical Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Tehri Dam</td>
<td>Old Dobata borrow area, District Tehri Garhwal, Uttarakhand</td>
<td>Quartzite, phyllite, sandstone, granite</td>
<td>Quartzite, tabular grains, equigranular, granoblastic in texture, leucocratic grey in colour, metamorphosed from sedimentary rock sandstone, quartz (96%), garnet (2%), muscovite (2%).</td>
</tr>
<tr>
<td>2.</td>
<td>Tehri Dam</td>
<td>New Dobata borrow area, District Tehri Garhwal, Uttarakhand</td>
<td>Quartzite, phyllite, shale, limestone</td>
<td>Quartzite, tabular grains, equigranular, granoblastic in texture, leucocratic white in colour, metamorphosed from sedimentary rock sandstone, quartz (99.25%), muscovite (0.5%), iron oxide (0.25%).</td>
</tr>
<tr>
<td>3.</td>
<td>Kol Dam</td>
<td>Kol, District Bilaspur, Himachal Pradesh</td>
<td>Quartzite, limestone, shale, sandstone</td>
<td>Quartzite, egigranular granoblastic in texture, medium grained, partially weathered, leucocratic in colour, quartz (97%), garnet (1%), muscovite, clay minerals, biotite and weathered iron oxide (0.5% each).</td>
</tr>
<tr>
<td>4.</td>
<td>Ranjit Sagar Dam</td>
<td>Shahpur Kandi, District Gurdaspur, Punjab</td>
<td>Quartzite, jasper, shale, conglomerate, claystone, Sandstone, grits of chart</td>
<td>Quartzite, granoblastic in texture, fine grained, melanocratic in colour, metamorphosed from calcareous sandstone, quartz (88%), calcite (5%), clay minerals (5%), muscovite (1%), amphibole (1%).</td>
</tr>
<tr>
<td>5.</td>
<td>Shah Nehar</td>
<td>At running distance (RD) 7410, near Sansarpur Terrace, District Kangra, Himachal Pradesh</td>
<td>Micaceous sandstone, quartzite</td>
<td>Micaceous sandstone, equigranular in texture, well rounded and elongated few pieces in orientation, quartz (88.5%), biotite (4%), muscovite (3%), amphibole (3%), weathered iron oxide (0.5%), iron pyrite (0.5%), pyroxene (0.5%).</td>
</tr>
<tr>
<td>6.</td>
<td>Western Yamuna Canal</td>
<td>Foundation of bridge, District Yamuna Nagar, Haryana</td>
<td>Quartzite, marbel, limestone</td>
<td>Quartzite, tabular grains, equigranular, granoblastic in texture, leucocratic white in colour, metamorphosed from sedimentary rock sandstone, quartz (92.5%), muscovite (3%), garnet (2%), clay minerals (2%), weathered iron oxide (0.5%).</td>
</tr>
<tr>
<td>7.</td>
<td>Western Yamuna Canal</td>
<td>Foundation of silt ejector site, District Yamuna Nagar, Haryana</td>
<td>Quartzite, limestone, shale, sandstone, phyllite</td>
<td>Quartzite, tabular grains, coarse-grained structure, inequigranular, granoblastic in texture, leucocratic in colour, metamorphosed from sandstone, quartz (97-98%), garnet (2%), iron oxide (0.1%).</td>
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<tr>
<td>1.</td>
<td>Kol Dam</td>
<td>Kol, District Bilaspur, Himachal Pradesh</td>
<td>Limestone</td>
<td>Sedimentary rock by chemical precipitation, having small fissures, gives effervescence with dilute HCl, grey in colour, fine grained, calcite (98.5%), muscovite (0.5%), weathered iron oxide (0.5%), clay minerals (0.5%).</td>
</tr>
<tr>
<td>2.</td>
<td>Purulia Dam</td>
<td>Purulia, West Bengal</td>
<td>Hornblende-quartz-schist</td>
<td>Partially metamorphosed from igneous rock of granitic origin, inequigranular, tabular in shape, schistose texture, mesocratic in colour, quartz (80%), hornblende (8%), hypersthene (8%), biotite (3%), calcite (1%).</td>
</tr>
<tr>
<td>3.</td>
<td>Parbati Dam</td>
<td>Kartah quarry, Sainj, District Kullu, Himachal Pradesh</td>
<td>Quartzite</td>
<td>Equigranular, granoblastic in texture, tabular in shape, slightly weathered near fissures, rest is fresh, quartz (90-91%), muscovite (8-9%), biotite (0.5%), weathered iron oxide (0.5%).</td>
</tr>
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Fig. 2: Location of the Project Sites on the Map (Obtained from www.mapsofindia.com)
Fig. 3: Grain Size Distribution Curves of Rockfill Material from Purulia Dam Site

Fig. 4: Uncompacted Void Content Apparatus

Fig. 5: UVC vs Maximum Particle Size for alluvial rockfill materials
6. Conclusion

The uncompacted void content can be determined in the laboratory for rockfill materials using an apparatus similar for fine aggregates.

It is observed that the UVC decreases with increase in maximum particle size for both types (alluvial as well as quarried) of the rockfill materials. It may be due to the fact that the increase in maximum particle size decreases the void content at same compactive efforts (Lambe and Whitman 1987).

References