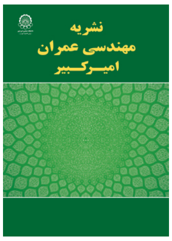

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Laboratory Investigation of Non-Darcy Flow through Rounded Porous Materials

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ABSTRACT: Application of aggregate coarse rockfill in hydraulic structures is increasing due to their special properties and is imperative due to its importance and their specific characteristics. Accurate investigation of the flow properties through coarse materials in order to determine hydraulic parameters is one of the most important necessities considering high application of such media in civil works. On the other hands, there is less works about transitional flow through coarse materials. In order to study the flow behavior through granular materials, a packed column test was built. Some experiments have done on three samples of rounded particles with average size of 10.348, 12.127 and 17.785 mm and seepage flow and upstream and downstream heads were recorded in a certain intervals. By using some calculating and depicting some graphs, their behaviors have evaluated. Using the relationship of flow velocity-hydraulic gradient, it was fund that such relationship is non-linear and this is a strong criteria confirming non-Darcy flow. The evaluating of results of this study by statistical indexes and its comparison by Ergun (1952), Kovacs (1981) and Sidiropoulou et al (2007) relationships showed that the relation of Sidiropoulou et al (2007) is more accurate than the other equations. The result of Reynolds number-friction factor curves showed that with increasing the grain size diameter, friction factor is decreased and Reynolds number is increased

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1- Introduction

Coarse porous media are encountered in a number of applications among many fields in science and engineering, such as rockfill dams, granular material, waste rock mines and high permeable geological formations. Particular characteristics of these media are large pores and high porosity values, which under some conditions may lead to high velocity flows. Under such conditions the applicability of linear theories to describe water flow has been evaluated extensively and corresponding modifications have been proposed (Sedghi-Asl 2010, Sedghi- Asl et al. 2014a).

When the flow regime is laminar and steady state, a linear relation between discharge and hydraulic gradient exists and Darcy's law is applicable.

Increased flow velocity, irregularities and excessive momentum transfer perturb the flow regime and gradually the flow becomes non-Darcian. A widely-used non-Darcy flow equation was presented by Izbash (1931) [1]. Another type of relationships is a second order equation, which was presented by Forchheimer (1901) [2]. Since the flow into coarse grains contain broad range of flow regimes, the quadratic form give better responses rather than power form. The equation of Forchheimer was presented as following:

$$i = AV + BV^2 \tag{1}$$

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Mc Corquodale et al. (1978) presented a general equation for non-Darcy containing the grain mean size, gravel particle size distribution, surface roughness, porosity and wall effects. Their dimensionless equations were represented based on 1250 experimental data obtained in permeameter with particles size between 55 mm to 79 mm and also Reynolds number varying from 0.001 to 20000. This equation is applicable for two flow regimes [3].

Sedghi-Asl and Rahimi (2011) represented a quadratic relationship using six different sizes of coarse materials (2.83 mm to 56.8 mm) under unconfined flow condition, based on the concept of pipe flows [4].

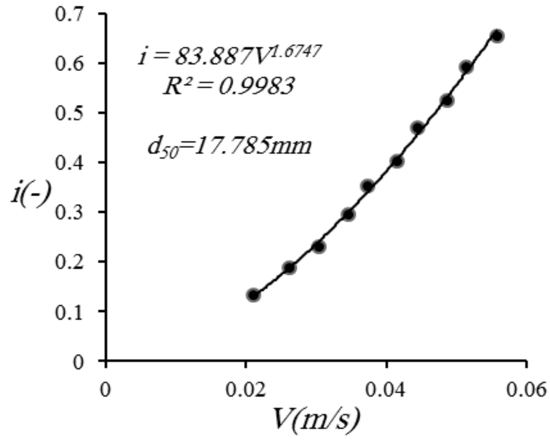
Although a number of works has been done on non-Darcy flow (Ward 1964, Hansen 1992, Ergun 1952 and …), but still more focuses is needed to describe and explain the properties and the behavior of flow in granular coarse materials especially in transition regime [5-7]. Transitional non-linear flow regime in porous media has received less attention in the past; therefore this paper aims to concentrate on the flow properties of the above-mentioned flow regime. The main objectives of this research are: 1- design and construct a packed column test for non-Darcy flow studies, 2- investigate experimentally the relationship between flow velocity and hydraulic gradient (head loss) in case of coarse aggregate, 3- assessment of the well-known head-loss equation.

2- Methodology

In this study, one type of aggregates including rounded grains with three different mean sizes were used as porous media. Porosity is one of the most important characteristics of coarse materials that have a key role in calculating and modeling of water level's profile. In fact, porosity is a distinction of modeling of water surface profiles in open channels and coarse porous materials. Therefore, its determination is important for accuracy of the calculations. The method of determination is the direct measurement which is used in this study. At first in the direct method, the particles are thrown into a container with a known volume and the chamber volume is considered as total volume (aggregate size and free space) and the needed water to fill the chamber is considered as pore volume of materials. By dividing the empty pore volume (the volume of water poured into the chamber) to total volume of container, porosity is calculated. Rounded materials have mean size of 17.78, 12.13, 10.35 and 6.53 mm, their porosity are 40.71, 39.78 and 38.64 %, respectively.

Packed column test components consisted of 5 whole parts including upstream tank, downstream tank, packed bed; piezometric board and measurement chamber of the flow rate (see Figure 1). The dimensions of upstream tank are 1 m × 0.50 m × 0.50 m and are made of glass which was placed inside a metal frame and also the dimensions of downstream tank are 0.50 m × 0.50 cm× 0.50 cm. The internal diameter of cylinder containing materials is 0.20 m and its length is 1 m. The packed bed was filled with selected granular materials and uniformly compacted. The packed column was then connected to two water tanks of adjustable levels at each end. By adjusting water levels in the upper tank, various flow rates and hydraulic gradients were established. Measurements were carried out after a steady state of flow was reached; in total 6 hours time was spent for each experiments (reading piezometric board and measuring seepage discharge). Scaled piezometric board was composed of 10 clear tubes tabs. Due to large grain sizes and voids, air bubbles exit through piezometers and water level in piezometers became stable after a short time. Finally, volumetric seepage discharge and piezometric pressures were measured at different time intervals and averaged for subsequent analyses (Figure 2).

Figure 1: General view of the experimental set-up used in this study



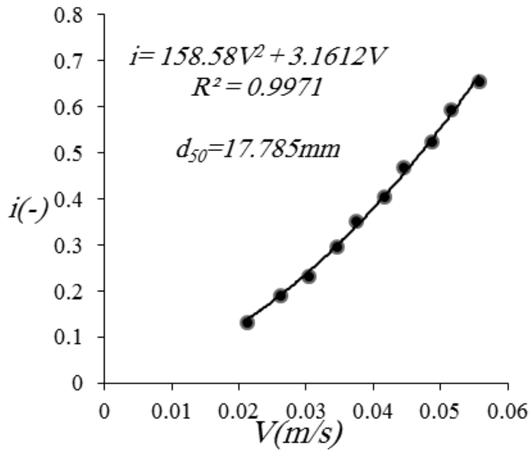


Figure 2: Non-linear relationships between hydraulic gradient and velocity by use of Forchheimer and Izbash equation for rounded materials

3- Conclusions

In the present article, 1-D non-linear flow was investigated experimentally and new data for analysis of the flow behavior have been obtained. Accuracy of the well-known non-linear relationships was verified in detail. Generally speaking, the following conclusions can be drawn:

- With increasing flow velocity, turbulency is increasing and kinetic conquer on more viscosity forces and tehrefore the friction factor decreases according to Moody diagram. For high Reynolds number , the friction factor is independent of the Reynolds number, which is in agreement with previous investigations (Stephenson 1979, Sedghi-Asl and Rahimi 2011).
- The relationship between velocity and hydraulic gradient indicate non-linearity of the relationship between flow velocity and the hydraulic-gradient that the same reason the why flow is non-linear or non-Darcy.

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