College of Geosciences

Department of Geology & Geophysics, College Station, TX 77843-3115
Hongbin Zhan, Ph.D.
Professor of Geology and Geophysics, Professor of Water Management and Hydrological Sciences
Holder of Endowed Dudley J. Hughes Chair in Geology and Geophysics
Tel: (979) 862-7961, Fax: (979) 845-6162, Email: zhan@tamu.edu

TEXAS A&M UNIVERSITY

January 19, 2022

Memorandum

To: Dr. Jorge Isidoro, Editor, Hydrology and Earth System Sciences

Subject: Revision of hess-2021-588

Dear Editor:

We have carefully revised our manuscript following all suggestions and comments of the reviewers. Thanks to the reviewers and editors, the manuscript has been improved substantially by addressing the constructive comments. The followings are responses to all the comments.

Response to Reviewer #1:

Minor comments

I have completed the review of the manuscript entitled "Experimental study of non-Darcian flow characteristics in permeable stones" submitted to HESS for potential publication. In my experience, experimental research on non-Darcy flow is never out of data. In this manuscript, firstly, the seepage experiment of permeable stone provides experimental basis for non-Darcian seepage in relatively low permeability medium; then, pore distribution characteristics of various permeable stones are analyzed by mercury injection test with Gaussian distribution function; finally, the influences of particle size and porosity on Forchheimer equation coefficient are investigated and some interesting phenomena are found. This manuscript has potential to provide hints for non-Darcy studies, in terms of such as critical values of non-Darcy flow, influences of pore properties on non-Darcy flow in some specific views and enlightenment of some special phenomena. At this stage, I will recommend a minor revision since there are still some deficiencies that need to improve in this manuscript as follows:

1. Line 159: The basic information of permeable stone related to the manuscript topic, such as forming background and porous properties or generation, should be introduced firstly.

Reply: Implemented. We have added the relevant application background and research status of permeable stone. Permeable stone is widely used in urban road design, sponge city construction and ecological effect research. And the most commonly used permeable base materials are large pore cement stabilized macadam, large diameter permeable asphalt mixture and so on. For permeable stone, there must be a certain connected pore space to maintain a certain permeability for transmitting water. However, the increase of pore space will lead to the decrease of pavement performance and mechanical strength. Therefore, many scholars have carried out a lot of research on controlling the proper pore space of permeable stone. Please see lines 179-187. In addition, we have outlined the preparation process of permeable stone. Please see lines 175-179.

2. Line 226: As Fig. 4 indicates, the best-fitting yields Forchheimer numbers (F0=B/A=kβρv/μ) with orders of magnitudes to be about -4, but Zeng and Grigg (2006) suggested a critical F0 to be 0.11 to trigger high-velocity non-Darcian flow, which makes the flow in authors' seepage experiment looks like "super-weak non-Darcian type". If so, the authors should compare the best-fitting performances between Forchheimer equation and simple Darcy's law, to prove the necessity of existence of the inertial term of Bq2.
(Zeng, Z., & Grigg, R. (2006). A criterion for non-Darcian flow in porous media. Transport in Porous Media, 63(1), 57-69. https://doi.org/10.1007/s11242-005-2720-3)

Reply: Implemented. In order to better compare with the actual groundwater flow, we converted the specific discharge to meters per day (m/d). Therefore, the best-fitting exercise yields Forchheimer numbers ($F_0 = B/A$) is about 10^{-4} according to Fig. 4, which is fairly small. In addition, the critical Forchheimer numbers proposed by Zeng and Grigg (2006) and Javadi et al. (2014) are empirical, in fact, the transition between Darcy to non-Darcy is successional over a certain range of Forchheimer numbers. The non-Darcian flow criterion applicable to different pore media is established by conducting seepage resistance experiments in homogeneous and heterogeneous porous media in our previous study (Li et al., 2017; Li et al., 2019), which is consistent with the results of Zeng and Grigg (2006). Please see lines 227-236.

3. Fig. 4: The results of best-fitting by Forchheimer equation have unconspicuous connection with the subsequent discussion of "pseudo" hydraulic conductivity and critical specific discharge.

Reply: Implemented. Generally speaking, the *q-J* and *q-K* curves are the most common methods used to analyze flow regime when conducting seepage resistance experiments in porous media. However, the nonlinear characteristics of *q-J* curve are not obvious due to the relatively small velocity range used in the experiments. The traditional hydraulic conductivity is the ratio of the specific discharge versus the hydraulic gradient (q/J), and it is a constant if Darcy's law is applicable, which is denoted as K_D (Li et al., 2019). In fact, the ratio of q/J is no longer a constant for the problems discussed in this study. In a word, the *q-K* curve can be used to observe the transition of flow state more intuitively. Please see lines 236-243.

4. Lines 299-300: The pressure ratio is a macroscopic parameter but the inhomogeneity is a relatively microscopic one, so the authors should prove the reasonability of PC/PB representing the inhomogeneity.

Reply: Implemented. It is well known that for mercury injection experiments, as injection pressure increases, the injection saturation will gradually increase and eventually all the pores will be filled with mercury. As can be seen from Fig. 7, with the continuous injection of mercury, the pressure of permeable stones with different particle sizes varies with saturation, which is reflected in the different pressure P_B and P_C at different stages. However, the reason for the different pressure is the difference of pore size distribution in the permeable stones. Therefore, the pressure ratio of B and C (P_C/P_B) can be used as one of the criteria to characterize the heterogeneity of pore size in porous media. We have made relevant revision on this matter, please see lines 336-343.

5. Equations (3-3) to (3-7) can be assembled into a single table for the purpose of more concise expression.

Reply: Implemented. We have summarized a series of equation coefficients in Table 4 and revised the sentences. Please see lines 437-440 and Table 4.

6. References should be provided for Equation (3-8). Eq. (3-8) cannot be derived from Eq. (1-2) alone.

Reply: Implemented. We have added the relevant references. For specific derivation process, please refer to previous studies (Huang, 2012). Please see lines 466-467.

Reference cited in this reply:
Huang, K.: Exploration of the basic seepage equation in porous media, PhD dissertation, 2012.
Javadi, M., Sharifzadeh, M., Shahriar, K., and Mitani, Y.: Critical Reynolds number for nonlinear flow through rougˆ walled fractures: The role of shear processes, Water Resources Research, 50, 1789-1804, https://doi.org/10.1002/2013WR014610, 2014.
Li, Z., Wan, J., Huang, K., Chang, W., and He, Y.: Effects of particle diameter on flow characteristics in sand columns, International Journal of Heat & Mass Transfer, 104, 533-536, https://doi.org/10.1016/j.ijheatmasstransfer.2016.08.085, 2017.
Li, Z., Wan, J., Zhan, H., Cheng, X., Chang, W., and Huang, K.: Particle size distribution on Forchheimer flow and transition of flow regimes in porous media, Journal of Hydrology, 574, 1-11, https://doi.org/10.1016/j.jhydrol.2019.04.026, 2019.
Zeng, Z. and Grigg, R.: A criterion for non-Darcy flow in porous media, Transport in porous media, 63, 57-69, https://doi.org/10.1007/s11242-005-2720-3, 2006.

Please contact me if you have further questions.

Sincerely Yours,

Hongbin Zhan, Ph.D., P.G.