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Reply to the Comment on “Numerical study on pore clogging mechanism in pervious pavements”

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1 Reply to the Comment on “Numerical study on pore clogging mechanism
2 in pervious pavements”

3 Ma Guodong¹, Zhang Jiong^{2,*}

4 **Abstract:** In this paper, to the best of our knowledge, we replied to the
5 comment on our published article “Numerical study on pore clogging
6 mechanism in pervious pavements” (Zhang et al., 2018). First, we solved
7 the problem about inappropriate descriptions to the cited papers and some
8 errors in equations. Second, we explained the relationship between fluid
9 cell size in CFD (computational fluid dynamics) and particle size in DEM
10 (discrete element method) in our CFD-DEM model, and we verified the
11 reliability and accuracy of our CFD-DEM model using single-particle
12 sedimentation case. It demonstrated that the CFD-DEM method used in
13 our study was acceptable.

14

15 **Key Words:** computational fluid dynamics; discrete element method;
16 pore clogging

17

18 **1. Reply to the “Inappropriate expressions.”**

19 The comments said that the references (Luo et al., 2015; Blais et al.,
20 2016; Li and Li, 2018) at the end of the sentence “*The commercial CFD*
21 *software of Fluent coupled with commercial DEM software of EDEM to*
22 *realize the connection of CFD with DEM*” would cause misunderstanding

23 to readers. In fact, what we initially mean is that all of these references
24 can realize the CFD-DEM coupled model, and using Fluent software
25 coupled with EDEM software to realize the connection of CFD with
26 DEM is only one of the choices. Also, Wu et al. (2018), Shao et al. (2013)
27 and Yu et al. (2018) realized the CFD-DEM modeling based on Fluent
28 and EDEM software.

29 In addition, the “volume of friction (VOF)” method should be
30 corrected as the “volume of fluid (VOF)” method (Hirt and Nichols,
31 1981).

32 **2. Reply to the errors of the “Mathematical equations.”**

33 The Eq. (6) in our paper should be corrected as

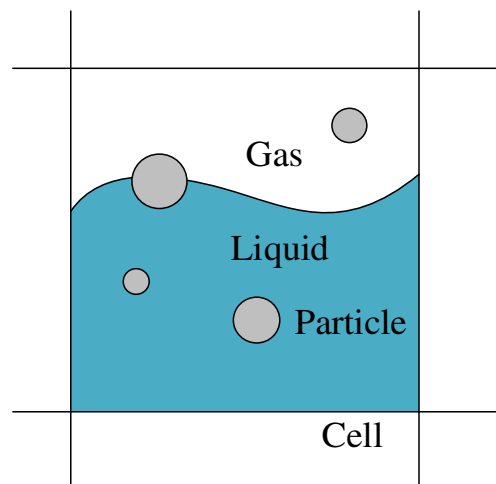
$$34 \quad \vec{f}_{fluid,i} = \vec{f}_{drag,i} + \frac{4}{3}\pi r^3 \nabla p$$

35 In fact, the VOF method used in our study is only for tracking the
36 interface between water and air. Wu et al. (2018) developed a DEM-VOF
37 method, and the continuity equation used for CFD-DEM coupled model
38 in his study is the same as ours. Therefore, the selection of continuity
39 equation in the water-air two-phase flow in CFD-DEM modeling should
40 be determined by the conditions.

41 Last but not least, the grid size in some region of our CFD-DEM
42 model is definitely a little bit smaller than the aggregate size. As
43 illustrated in the comment on “Numerical study on pore clogging
44 mechanism in pervious pavements,” it will cause inaccuracy to some

45 degree when calculating the porosity in fluid cells using unresolved
46 CFD-DEM approach. However, the results in our CFD-DEM modeling
47 are acceptable, and the reasons are as follows:

48 First, as introduced in the paper of Sun and Sakai (2015), a typical
49 gas–solid–liquid flow (shown in Fig.1) involves fluid–fluid interaction
50 (evolving fluid interface), fluid–solid interaction (fluid–particle
51 momentum exchange) and solid–solid interaction (particle–particle
52 collision).

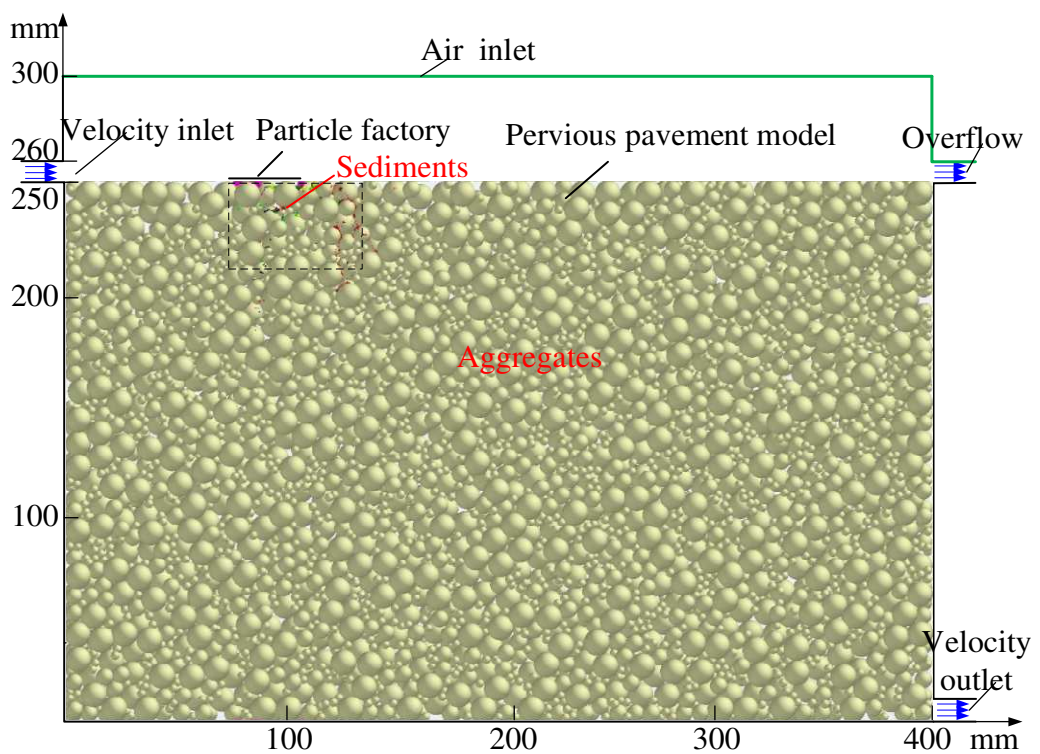


53

54 Fig.1 The gas–solid–liquid flow in a fluid cell

55 To the best of our knowledge, the core of our study is to observe the
56 sediments clogging in the pervious concrete. Thus we focus only on the
57 fluid-solid interaction, especially the water-sediment interaction. In our
58 CFD-DEM model (shown in Fig. 2), the particles (aggregates) with a
59 diameter of 4 mm, 8 mm and 12 mm are bonded to form the pervious
60 concrete pavement, and these particles are fixed and cannot have any
61 motions. The interface between water-gas is stable and above the

62 pervious concrete pavement model (as depicted in Fig.3). Therefore,
63 aggregate-gas interaction and sediment-gas interaction are neglected in
64 our CFD-DEM model. Even though there are water flow into the pores of
65 the pervious concrete pavement, this study does not analyze these
66 interactions including the aggregate-water interaction, because these
67 factors exert little influence to sediment-water interaction.



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Fig. 2 The CFD-DEM model

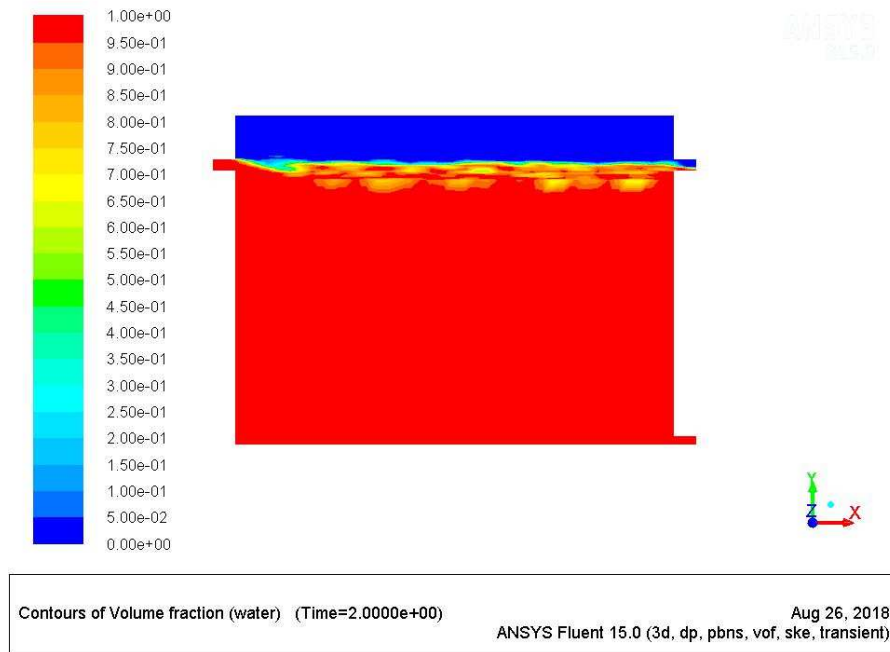


Fig.3 The interface between water and air

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72 Second, as shown in Fig. 4, the grids in region A and B are refined to

73 observe the interface between water and air. It is evident that the grid size

74 is small, but the grids contain no particles. Therefore, it does not violate

75 the rule of unresolved CFD-DEM approach and would not influence the

76 CFD-DEM simulation. The grids in region C are also refined to observe

77 the interface between water and air, and they contain some aggregates

78 and sediments. The grid size is smaller than the aggregates (12 mm

79 diameter), which may cause inaccuracy to the CFD-DEM simulation.

80 However, as mentioned above, the aggregates are fixed and have no

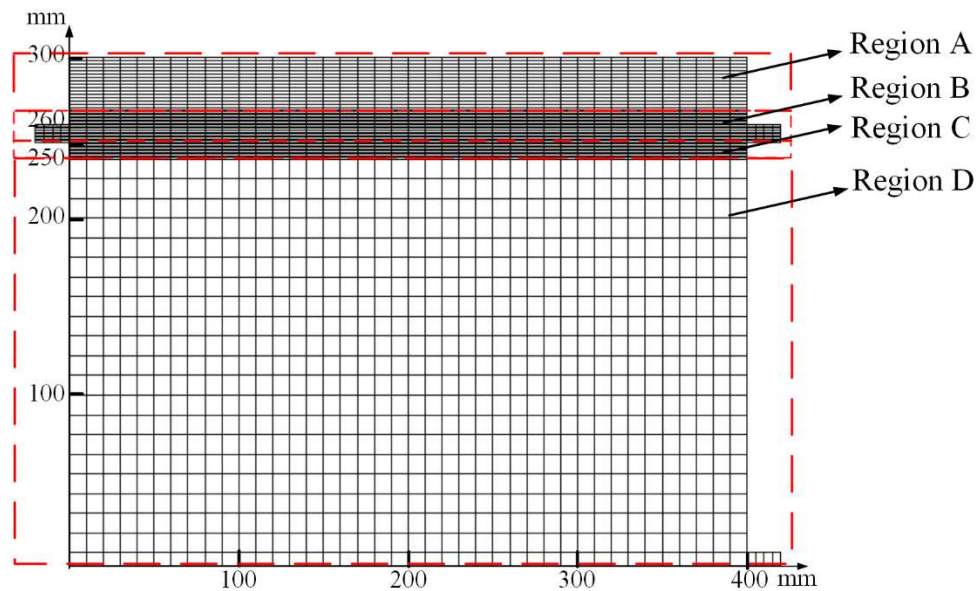
81 motions. In this study, we do not consider their influence on the

82 CFD-DEM modeling. Most importantly, the grid size in region C is still

83 larger than the particles of sediments. Last, the grid size (appropriately 10

84 mm) in region D is just a little bit smaller than the aggregate size. It will

85 not change the motions of sediments significantly, and the reasons are the
86 same as above mentioned. Therefore, it is credible to model the sediments
87 transport using our CFD-DEM model.



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Fig. 4 The grid size of CFD-DEM model

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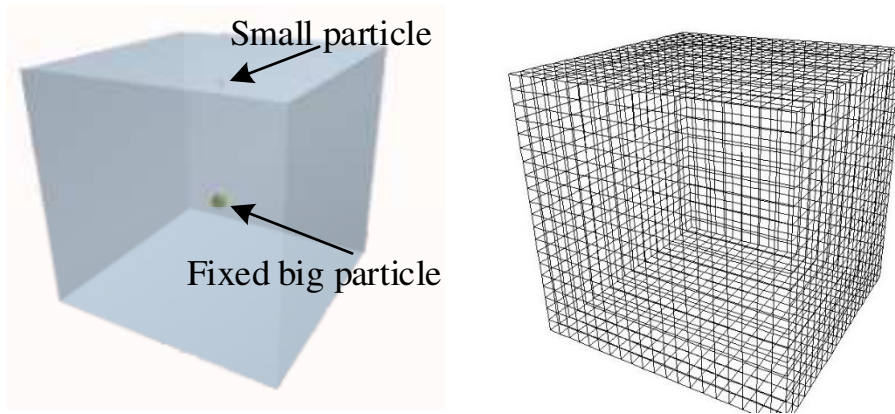
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Furthermore, we used single-particle sedimentation simulation to validate the CFD-DEM method used in our study. As shown in Fig.5, the tank is full of water, whose dimensions are 200 mm × 200 mm × 200 mm. The walls of the tank are defined as nonslip boundary conditions. A small particle (diameter 3 mm) is placed 180 mm high from the bottom surface, and it will fall freely until colliding with a fixed big particle (diameter 12 mm, placed 80 mm high from the bottom surface) in the water. The density of particles is 2650 kg/m³. The viscosity and density of the water are 1×10⁻³ Pa·s and 1000 kg/m³, respectively. The grid size is set as 40 mm, 20 mm, and 10 mm separately to observe the effect on the motion of single-particle. In CFD simulation, the standard k-ε turbulence

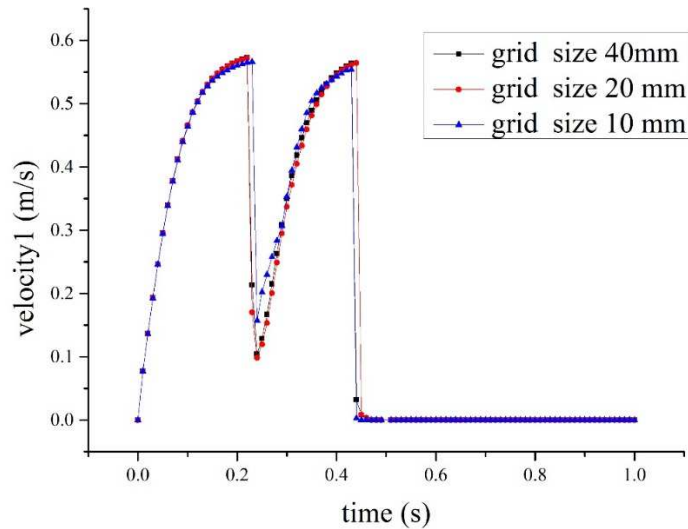
101 model and PISO (Pressure Implicit with Splitting of Operator) method are
102 used. The time step of DEM simulation is 2×10^{-5} s, and the time step
103 of CFD simulation is 2×10^{-4} s.



104

105 Fig.5 The single-particle sedimentation in water and grid

106 Fig.6 shows the results of the single-particle sedimentation
107 simulation. As shown in Fig.6, the grid sizes of 40 mm and 20 mm are
108 larger than the particle size while the grid size of 10 mm is smaller than
109 the particle size. However, results show the velocities of single-particle in
110 different grid size are almost the same. Moreover, all of the parameters
111 and configuration of single-particle sedimentation simulation are the
112 same as the CFD-DEM model in our study. Consequently, it
113 demonstrated the results using the current grid size (Fig.4) in our
114 CFD-DEM model are acceptable.



115
116 Fig.6 The velocity of single-particle in different grid size

117 In our further study, we will investigate the CFD-DEM coupling
118 modeling methodology and contrast the numerical results using different
119 CFD-DEM method such as the resolved, unresolved, and semi-resolved
120 method.

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