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Grout diffusion characteristics during chemical grouting in a deep water-bearing sand layer

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ABSTRACT

The deep, loose bottom aquifer of the eastern air shaft in the Xinglongzhuang Coal Mine was used to develop an experimental model of shaft grouting through Model deep soil. Lab experiments using chemical grouting were done to study the grout. The grouted soil shapes and osmotic pressure were measured during the experiments. The tested characteristics of the grouted soil show that the diffusion mode of grout in saturated sandy soil is a combination of split compaction and osmosis. More specifically, the shape of the grouted soil is determined by split compaction while the size of the grouted soil shape is determined by osmosis. Sensor test results indicate that the main reason for the non-uniform grout diffusion is the anisotropic osmotic pressure field surrounding the grouting holes.

1. Introduction

Among the 300 vertical shafts located in large-scale coal mines in eastern China, including Huaibei, Xuzhou, Zaozhuang, and Yanzhou, over 80 shafts are located in deep loose aquifers and have been damaged by a new non-mining geological hazard, namely vertical shaft wall fracturing. As a result of fractures the deformed shaft and contracted shaft section make it difficult to convey material. If more severe, the mine must be shut down due to shaft wall fracture and sand and water spewing. Therefore, this hazard affects normal production and also brings about huge economic losses and potential safety hazards. This problem is regarded as one of the biggest mine geological hazards by mine construction field workers that has been encountered since mine construction began [1–8].

The shaft damage mainly occurs in eastern coal mines dug in thick alluvium. The loose soil layer in these areas has a thickness from 200 to 800 m. The geological engineering properties allow the area to be roughly divided into four aquifers and three aquifuges. The bottom aquifer is commonly fractured, which requires grout treatment. The unequal grain composition in the bottom aquifer, and many particles and clays, makes the osmosis property very inferior. As a result particle model cement grout cannot be used [9–15]. Engineering practice has shown that urea resin grout is very effective for handling the bottom aquifer. Therefore, a study of the diffusion characteristics of a urea resin grout located in a sand layer is of a great significance. This will provide information to help handling shaft wall fracturing hazards and to enhance grouting operations in low osmotic sand.

The deep, loose bottom aquifer located at the eastern air shaft in the Xinglongzhuang Coal Mine was used to develop an experimental model of grouting through the shafting discussed herein. Urea resin is used as the grout during chemical grouting experiments in saturated sand to study the diffusion of the grout.

2. Experimental

2.1. Physical index of the aquifer around the shaft at the west air shaft in Xinglongzhuang Coal Mine

The fourth loose soil in this coalfield has seven composite structures that include aquifers and aquifuges. Its thickness is 184.1 m. The physical index is shown in Table 1.

2.2. A model material

The shaft well diameter in the Xinglongzhuang Coal Mine is 5.4 m. It has double concrete shaft linings 0.45 m thick at the outer layer and 0.5 m thick for the inner one. This test stimulates the diffusion of single borehole grout without considering the influence of porous grouting effects. In other words, this test is similar to the prototype of the single borehole chemical grouting test. Taking the above conditions into consideration, the size of the model is 1270 mm × 1000 mm × 1000 mm (L × B × H). It is shown in Fig. 1.

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Table 1
Physical properties of the soil from the aquifer layer at the east air shaft of Xinglongzhuang Coal Mine.

Grain composition (mm, %)						Porosity ratio	Dry unit weight (kN/m^3)	Osmotic coefficient	Proportion
Sand			Particle		Clay				
2–0.5	0.5–0.25	0.25–0.074	0.074–0.01	0.01–0.005	0.005				
56	16	15	10	2	1	0.74	14	4.3×10^{-4}	2.6

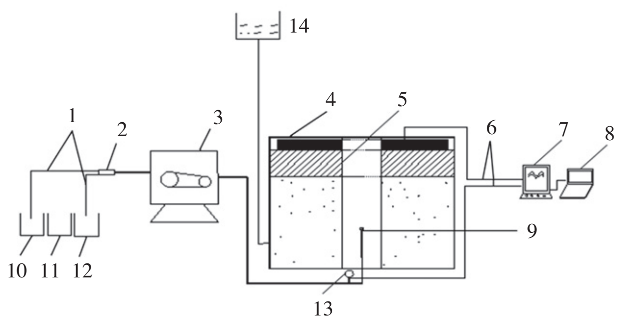

Fig. 1. A schematic of the test model. (1) Feed: grout components A and B; (2) Hybrid T; (3) Grouting pump; (4) Box; (5) Simulated shaft wall; (6) Data collecting cables; (7) Data acquisition equipment; (8) Data processing system; (9) Grouting orifice; (10) Liquid A; (11) Clean water; (12) Liquid B bucket; (13) Grouting pressure sensor; (14) Water tank.

The gradation and osmosis of the soils used in this test approximate those of the field soils. See Table 2. The grout used is based on the prototype. The adopted grouting pump is a mini type with a size of 0–4 MPa. Restrictions of the interior conditions limit the water head to 2 m, in line with the pore water pressure. This is shown in Fig. 1.

The model was welded from 6 mm steel plate. The welding seams were waterproofed to ensure the compactness of the box as shown in Fig. 2.

2.3. Experimental equipment

The equipment shown in Fig. 1 was used to obtain the shape of grouted soil and the grout osmotic pressure in the soil. There are three systems: the grouting system (1, 2, 3, 10, 11, 12); the model box (4, 5, 9); and, the detection system (6, 7, 8, 13). The model box has the lower aquifer as 700 mm of sand and the upper aquifuge as 200 mm of clay.

2.4. Experimental process

(1) Gradated sand 700 mm thick is compacted into the box by layers. The physical parameters of the sand are shown in Table 2.
(2) The sensor is installed.

The 200 mm of bentonite clay is the pan above the sand. A 5% quick lime addition to the clay makes the whole structure compact and concrete after the water is poured.

The counterweight added to the clay pan makes the overburden pressure on the grouting hole in the horizontal soil layer 2 kPa. After solidification of the soil mass for two to four days in the airtight experimental box the pore water pressure is increased. When the pressure stabilizes the grout pump starts so as to begin the experiments. Liquid A is a urea resin and liquid B is an 8% oxalic acid solution. The proportion for double liquid grouting is A:B of 10:3. The parameters of the urea resin are shown in Table 3.

Table 2
Physical properties of the soil used in the model aquifer.

Grain composition (mm, %)						Porosity ratio	Dry unit weight (kN/m^3)	Osmotic coefficient	Proportion
Sand			Particle		Clay				
2–0.5	0.5–0.25	0.25–0.074	0.074–0.01	0.01–0.005	0.005				
62	17	15	5	1	1	0.72	13.4	6.3×10^{-4}	2.6

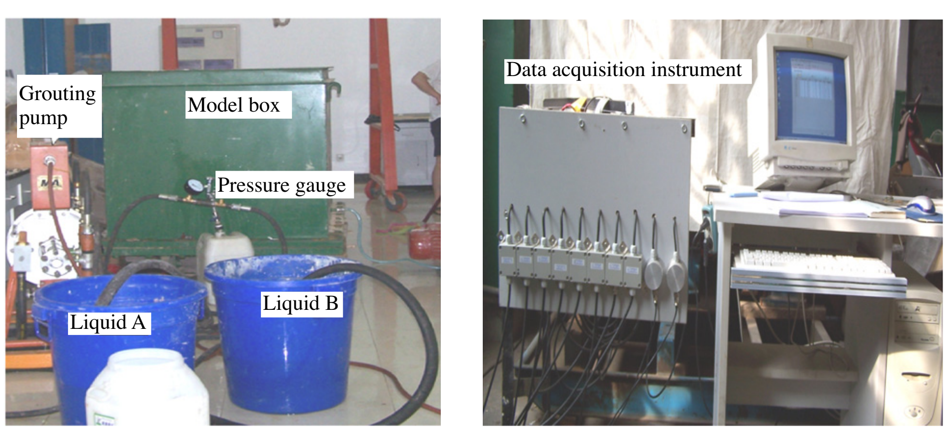

Fig. 2. Test model.