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Technical Note

Effects of mudstone particle content on compaction behavior and particle crushing of a crushed sandstone–mudstone particle mixture

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ABSTRACT

The present study focuses on the compaction behavior and particle crushing, during the compaction, of a crushed sandstone–mudstone particle mixture. Compaction tests and sieve analysis tests, in laboratory, were performed. The effects of the mudstone particle content, by weight, on the maximum dry density, the optimum moisture content and the average relative breakage were analyzed. Testing results indicate that the values of the maximum dry density and the optimum moisture content of the mixture are increasing then decreases with the increase of the mudstone particle content. While the mudstone particle content is about 60%, the maximum dry density is near its maximum. The average relative breakage, during the compaction, is decreasing quickly then increases slowly with the increase of the mudstone particle content. While the mudstone particle content is about 40%, the average relative breakage is near its minimum. Compared to those of a crushed sandstone particle mixture, the maximum dry density of the crushed sandstone–mudstone particle mixture is greater, and the average relative breakage, during the compaction, is smaller.

1. Introduction

Interbedded strata of mudstone and sandstone are widely distributed around the world, and also in Chongqing of China. The interbedded deposit of mudstone and sandstone in Chongqing of China was mainly formed in Upper Triassic, Jurassic, and Lower Cretaceous periods (CGMREDC, 2002). The thickness of the interbedded deposit formed in Upper Triassic period, which is called as the Xujiahe formation, is about 250 m to 650 m. The interbedded deposit formed in Lower Jurassic period includes the Zhenzhuchong formation with 180 m to 320 m in thickness, and the Ziliujing formation with 300 m to 420 m. That formed in Middle Jurassic period includes the Xintiangou formation with 40 m to 490 m, and the Shaximiao formation with 1100 m to 2100 m in thickness. That formed in Upper Jurassic period includes the Suining formation with the thickness of 200 m to 600 m, and the Penglaizhen formation with 124 m to 1300 m. The interbedded deposit of mudstone and sandstone formed in Lower Cretaceous period is called as the Wotoushan formation, and its thickness is about 100 m to 560 m.

In actual engineering works, the method to excavate the formation is usually the combination of the explosive blasting excavation and the mechanical excavation. The rock blocks of mudstone and sandstone, which are excavated from mountains or foundation ditches, are naturally mixed together, not artificially, because of the interbedded deposit structure. The mixture of crushed sandstone and mudstone particles is often used as a main filling material in many geotechnical engineering works such as embankment, slope and foundation. Evaluation on the compaction quality of the mixture is very important. Many factors, such as soil type, compactive effort and particle shape, may affect the compaction quality of soils (Hamdani, 1983; Blotz et al., 1998; Cho et al., 2006). Many other behaviors of soils, such as shear strength (Wang et al., 2013c, in press), compressive deformation, permeability (Yan et al., 2010; Wang et al., 2012, 2013a), angle of repose (Wang et al., 2013b), and even fracture behavior (Wang et al., 2007a,b), may also be affected by soil density and/or water content. The soil particles may be crushed during the loading (Hardin, 1985; Lade et al., 1996; Coop et al., 2004; Lobo-Guerrero and Vallejo, 2005; Casini and Viggiani, 2011). And the particle crushing during the loading may be induced by some factors, such as the applied stress, the initial grading of the tested soil (Coop et al., 2004) or that of the artificial crushable material (Casini et al., 2013), and the change in water content (Jamei et al., 2011).

The mixture of crushed sandstone–mudstone particles is often used as a main filling material in many geotechnical engineering works, but the investigation on its compaction behavior isn't enough. So far, the problem of the particle crushing during compaction for the sandstone–mudstone particle mixture hasn't been given attention. In

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the present study, the compaction behavior of the crushed sandstone–mudstone particle mixture is investigated. And a special attention is also paid to its particle crushing during the compaction.

2. Tested materials and testing methods

2.1. Tested materials

The lightly weathered sandstone and mudstone blocks, which were in the Shaximiao formation formed in Middle Jurassic period and excavated from a rocky mountain along the Yangtze River in Chongqing of China, are used. The uniaxial compressive strengths tested in laboratory of the mudstone are 17.6–25.8 MPa (natural state) and 8.3–15.0 MPa (saturated state), and those of the sandstone 60.0–72.2 MPa (natural state) and 60.0–67.4 MPa (saturated state). The dry densities of the mudstone and sandstone, which are determined in laboratory, are 2.358×10^3 kg/m^3 and 2.345×10^3 kg/m^3, respectively.

The rock blocks are crushed into particles with different sizes less than 20 mm for the purpose of preparing the tested materials. The procedure to crush the rock blocks includes two steps. Firstly, the rock blocks are artificially crushed into particles less than 60 mm in diameter using iron hammers and steel piercers. Then, the artificially crushed particles are mechanically crushed again into particles less than 20 mm in size by a special rock breaker. The procedures to crush the mudstone and sandstone blocks are the same, but the needed energies are very different because of the difference in compressive strength of the two different rocks.

The crushed sandstone particles and mudstone particles are respectively separated into 8 groups based on the particle sizes 20–10 mm, 10–5 mm, 5–2 mm, 2–1 mm, 1–0.5 mm, 0.5–0.25 mm, 0.25–0.075 mm, and <0.075 mm. The particle groups of sandstone and those of mudstone are respectively mixed according to the grain size distribution curve shown in Fig. 1. The grain size distribution of the excavated material in the field may be different from different formations, but as a filling material, its grain size distribution may be determined or designed by engineers. In the present study, the grain size distribution of the tested materials shown in Fig. 1 is obtained from an actual filling material in Chongqing according to the similar grading method suggested by the standard method for sample preparation of coarse soil (Trade Standard of P. R. China, SL237-053, 1999). In the Chinese standard method, there are three methods to prepare the tested soil based on the grain size distribution of the actual coarse soil which contains oversized particles. They are scalping method, equivalent weight replacement method, and similar grading method. The scalping method is to discard the oversized particles from the actual coarse soil. The equivalent weight replacement method is to replace the oversized particles with equivalent weight particles smaller than the maximum size, which is determined according to the size of the test apparatus, and greater than 5 mm. The similar grading method is to reduce the particle size of the actual coarse soil according to the two principles. One is that there isn't any oversized particle in the new tested soil. The other is that the coefficient of uniformity of the new tested soil is equal to that of the actual coarse soil.

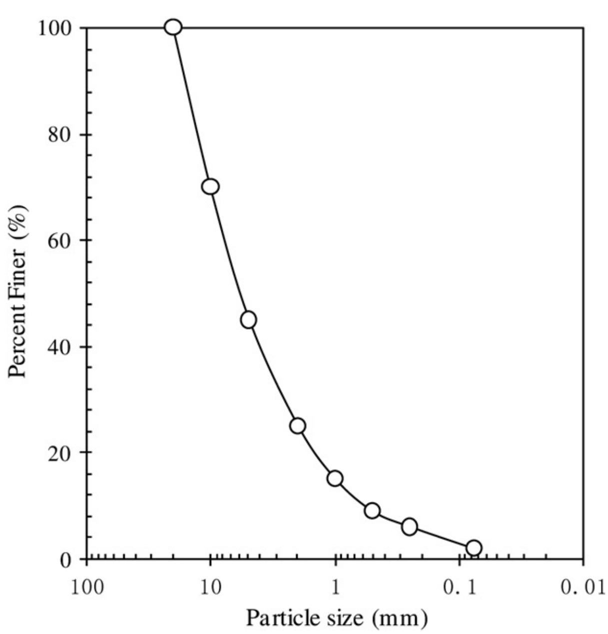

Fig. 1. Grain size distribution curve of tested material.

Four tested materials, crushed sandstone–mudstone particle mixtures, are prepared by mixing the sandstone particle (SP) mixture and the mudstone particle (MP) mixture together according to the weight ratio of SP to MP 8:2, 6:4, 4:6 and 2:8. In order to analyze and compare conveniently, another two tested materials, crushed sandstone particle mixture only (or the weight ratio of SP to MP is 10:0) and crushed mudstone particle mixture only (or the weight ratio of SP to MP is 0:10), are also prepared. The grain size distribution curves of the six tested materials, which are four crushed sandstone–mudstone particle mixtures, one crushed sandstone particle mixture only and one crushed mudstone particle mixture only, are the same with the curve shown in Fig. 1.

2.2. Testing methods

In order to investigate the compaction behavior of the mixture, a compaction test in laboratory, based on the standard method for moisture–density test of soil (Trade Standard of P. R. China, SL237-011, 1999), is used. The compaction device mainly consists of a compaction mold and a compaction hammer. The size of the compaction mold is 152 mm in inner diameter, 116 mm in inner height and 2103.9 cm^3 in volume. The weight of the compaction hammer is 4.5 kg, and its base diameter is 51 mm. In testing, the tested material is compacted in the compaction mold by the compaction hammer in five equal layers. The drop height of the hammer is 457 mm, the compacted number for each layer is 56, and the compactive effort is 2684.9 kJ/m^3. Before compaction, the tested soils with different water contents are stored in several sealed containers for about 24 h.

In order to determine the grain size distribution curves of the tested materials before and after compaction, a sieve analysis test in laboratory, based on the standard method for particle size distribution of soils (Trade Standard of P. R. China, SL237-006, 1999), is used. In the Chinese standard method, there are three methods to determine the particle size distribution of soil. They are sieve analysis method, density meter method, and suction pipette method. The sieve analysis method is suitable for the soil of which the particle size is greater than 0.075 mm, and the other two methods are suitable for the soil less than 0.075 mm. In the sieve analysis test, the sieving machine, which mainly consists of a sieve shaker and a set of sieves with different size round holes, is the key equipment. In the present tests, eight sieves with 20 mm, 10 mm, 5 mm, 2 mm, 1 mm, 0.5 mm, 0.25 mm and 0.075 mm in diameter of round holes, respectively, are used. And the shaking time in the sieving machine is about 10 to 15 min.

3. Testing results and analyses

3.1. Compaction behavior

The moisture–density curves, obtained from the compaction tests, are shown in Fig. 2. The value of the maximum dry density of the crushed sandstone–mudstone particle mixture (the weight ratios of SP to MP are 8:2, 6:4, 4:6 and 2:8 in Figure 2) ranges from 2.120×10^3 kg/m^3 to 2.175×10^3 kg/m^3, and that of the optimum