다양한 실험방법의 적용에 따른 사질토의 최대 및 최소밀도
Maximum and Minimum Densities obtained from Various Test Methods on Cohesionless Soils

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개요 : 사질토의 최대/최소 밀도는 사질토 지반의 중요한 물리적 특성인 상대밀도를 결정할 때 이용된다. 그러나 최대/최소 밀도를 결정하는 방법에는 여러 가지가 있으며, 각 방법들에 따라 결정되는 값도 달라진다. 본 시험에서는 여러 시험방법의 최대/최소 밀도를 비교하는 연구를 수행하였다. 본 연구에서 적용된 최대밀도 결정방법은 ASTM, JIS, Simplified 방법 및 Air pluviation 방법이며, 최소밀도 결정방법은 ASTM, JIS 및 Slurry 방법이다. 시험모래는 부산지역에서 얻어진 3가지 모래시료를 이용하였다. 시험결과, Air pluviation 방법이 가장 큰 최대 밀도값을 주었으며, JIS 방법이 가장 작은 최소 밀도를 나타내었다. 또한 최대밀도를 위하여 JIS 및 Simplified 방법으로 적용한 후 추가적인 다짐을 수행한 결과, Simplified 방법이 입자의 파괴나 입자간의 분리효과 없이 가장 큰 최대밀도를 나타내었다.

주요어: 사질토, 실험방법, 최소 밀도, 최대 밀도

1. Introduction

The maximum and minimum densities, also known as the limit densities, represent the states of densest and loosest packing of sand. The limit densities are used to evaluate the relative density which is an important basic physical property for cohesionless soils. The small variation in the maximum or minimum densities can bring a large difference in the relative density. Therefore, the proper evaluation of the limit densities is important.

In addition, the ASTM method (same with KS F 2345) is widely used to get the limit density but the method requires the large volume of sand sample, which is usually difficult to obtain from conventional sampling methods. This limitation has provoked to find the other alternative methods.

In this study, four methods including ASTM method, Japanese Standard method (JIS A 1224: 2000), air pluviation method and simplified method were selected for the maximum density, and three methods including ASTM method, Japanese standard method and slurry-based method were selected for the minimum density. Three kinds of sands were used for the tests. More than ten tests in each method, except ASTM and slurry-based method, were performed to improve the reliability of tests. Finally, the limit densities from each method were compared each other.

2. Test methods

2.1 Maximum dry density

Methods applied for the maximum density of the sand are as follows.

The ASTM (D 4253, 2000) is the most popular method for the limit densities. In this method, the standard mold of 152.4 mm inner diameter and 155.2 mm height is filled with oven dry sand sample. The surcharge of 14 kPa (25.6 kg) is applied and then subjected to the vertical vibration with 60 Hz (or 50 Hz) frequency for the period of 8 min. (or 10 min.). The maximum density is then calculated using the weight of the densified sand and the volume of the mold. However, the ASTM method requires large volume of sample. Besides, Presti et al. (1992) reported that the method is possible to occur the crushing and segregation of sands.

The Japanese standard method (JIS A 1224, 2000) requires comparatively very less volume of sample (about 200 g which is comparable with more than 5 kg for the ASTM). In this method, the mold (60 mm in inner diameter, and 40 mm in height) and collar (20 mm in height) are used. The oven dry sample is placed by 10 layers in the mold. In each layer, horizontal tapping is applied at 20 points around the mold using a 70 g wooden hammer and 5 hits per second at each point are applied.

The simplified method (Muszynski, 1999) was recently suggested in order to determine the limit densities of clean poorly graded fine to medium sand. The mold, made by a 4 mm thick PVC pipe, has 4.2 cm inner diameter and 6.6 cm height. The freely moving coins placed inside the holder, is used as a surcharge (total weight = 50g) which can generate vibration during tapping. The horizontal tapping is applied using a 70 g, 20 cm long wooden dowel. Five layers of sand are placed in the mold; at each layer tapping is applied at the mid point of the mold at a rate of 4 times per sec during the period of 10 sec, with a slowly and continuously rotating the mold. Muszynski indicated that the ASTM method produces a greater maximum density than the simplified method for a uniform sand with fines and a well-graded fine to coarse sand, whereas for the fine to coarse grained, graded sand. And, the simplified method produced higher maximum density.

To apply the simplified method, the mold was made from plexiglas with internal diameter of 50 mm instead of 42 mm based on the study of Brand (1973), who noticed the erratic density values where a small cylinder (D=3.87 cm) was employed due to the significant side friction effects.

In the air pluviation method, the dry sand kept in the stationary hopper and is allowed to rain into the mold from a certain height. The density is controlled by the depositional intensity, the uniformity of sand rain and the height of deposition. Depositional intensity is controlled by the nozzle diameter of the hopper. Miura & Toki (1982) indicated that the height of fall has insignificant effect unless the height of fall is very low (< 50 cm). For the uniform sand rain, multiple sieves are used as a diffuser. Air pluviation method is more effective for the uniform sand or sand with fewer fines. For the well graded sands, Lo Presti et al. (1992) used the vacuum pluviation fines. F or avoid segregation. They alsr used andfor 13 different types of sands ranging from fine to sandy gravel and sand with various percentage of non-plastic silt. The results showed that the air pluviation method produced a higher dry density than the ASTM method, with less effect of particle crushing and segregation. Cresswell et al. (1999) indicated that for the coarse grained sands, the pluviation density was greater than that achieved by the vibrating hammer test (BS 1377), while for the medium grained sands the pluviated density is low.

In the present study, the hopper with a 3 mm opening was used to achieve the minimum depositional intensity which was the possible minimum size for the free and constant sand flow. The height of sand drop was set at 110 cm. Five sieves with the opening size of 2 mm were used as a diffuser. The upper two sieves were kept 3 cm apart, while the other sieves 2 cm apart. The mold was used as the same one used in simplified method.

2.2 Minimum dry density

Methods applied for the minimum density of the sand are as follows.

In the ASTM (D 4254: 2000) method, dry sand is poured into the standard mold by a 150 mm long spout (tube) with a 13 mm or 25 mm spout in size. In the Japanese standard method, the conical device with a 12 mm opening is used to pour the dry sand into the mold. The simplified method also uses similar approach as the Japanese standard method and thus discarded in this study.

Muszynki (1999) showed that the ASTM (D4254: 2000) produced the lower minimum density for the well-graded sand, whereas the simplified method produced the lower minimum density for the uniform sand. For the graded sand, both methods produced a similar result.

Carraro and Prezzi (2008) developed the slurry-based method to determine the minimum density of the sands containing fines. In this method, sand samples are allowed to settle in a vertical cylindrical plexiglas tube filled with water. Carraro and Prezzi (2008) showed that for the clean sands and silty sands, the slurry-based method gave lower minimum density than ASTM method, whereas for the clayey sands, ASTM gave the higher minimum density.

3. Tested sand samples

Three types of sands were used. The two types of sands, Myungji sand (MJ sand) and Hwajeon sand (HW sand), were obtained from the upper sand layer in the Nakdong deltaic area, Busan. However, these sands were insufficient for the density determination only by ASTM. Thus, for a comparison study, another sand at the construction site (MJ-2) was collected which is physically very similar to MJ sand. Table 1 shows the main physical properties of three sand samples tested in this study. Figure 1 shows the grain size distribution of these sand samples. The MJ and MJ-2 sands were yellowish gray in color and fine to coarse in size. The HW sand was greenish gray and fine to medium in size. Base on the Unified Soil Classification System, all three sands were classified as poorly graded sand (SP); however, the MJ and MJ-2 sands were more well-graded than the HW sand.

Table 1. Physical properties of tested sands

	Soil description	G_s	Fine content %	C_u	C_c	D_{50} (mm)	D_{10} (mm)
MJ sand	Yellowish gray, fine to coarse grain	2.662	1.24	2.58	0.97	0.24	0.11
MJ-2 sand	Yellowish gray, fine to coarse grain	2.658	0.25	1.56	1.10	0.31	0.17
HW sand	Greenish gray, fine to medium grain	2.668	0.84	2.15	1.15	0.20	0.10

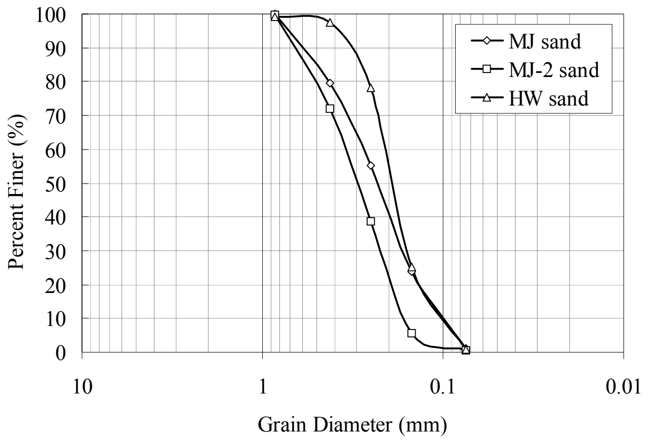


Fig. 1. Grain size distributions of tested sands

4. Test Results

The maximum and minimum densities from the tests are summarized in Table 4-6. The tests were conducted at least 10 times in all methods except the ASTM and slurry-based methods. The coefficient of variance (COV) was less than 0.5 % which indicates less variation. The general trend of the results showed that the Japanese and the simplified methods produced the similar values of maximum density. The ASTM method produced the least maximum density for the MJ-2 sand. Although two tests were performed by ASTM, the data showed a less variation (COV = 0.23%). Among the alternative methods, the air pluviation method produced the highest maximum densities among all three sands, whereas the JIS method produced the least maximum density for the MJ and MJ-2 sands.

In the case of maximum densities, the maximum differences among three methods except ASTM were 2.68% in the MJ sand, 2.17% in the MJ-2 sand and 3.47% in the HW-sand. In the case of minimum densities, the JIS method produced low minimum densities in all sands. For the minimum density, the slurry-based method produced 8.23% higher than the JIS method on MJ sand, 5.85% in the MJ-2 sand and 6.62% in the HW sand. Although the ASTM and JIS methods use a similar procedure in minimum density determination, the later gave about 3.65% lower minimum density than the ASTM.

From the test, it was also found that the higher maximum densities from the JIS and the simplified methods can be achieved by slightly modifying the suggested procedure. For this purpose, on the first step, the additional densification process was simply repeated on previously densified sand. After taking weight of densified sample, the collar was replaced on the mold with earlier densified sample, then again placed the new sand layers in the collar and repeated additional densification process. The process was repeated until constant maximum density was obtained. In this way, the maximum density was increased up to 1.97% (avg. 1.51%) in the case of JIS method and in the case of simplified method; the maximum density was increased up to 2.52 % (avg. 1.17%). In the second step, the number of tapping was increased. In the JIS method, the tapping points were increased to be from 20 to 30 and in the simplified method, the tapping duration was increased from 10 second to 20 second. By increasing the tapping number, the increase in the maximum densities was found 2.28% (avg. 1.22 %) in the case of JIS method and 2.06% (avg. 1.84%) in the case of simplified method. The number of tapping can not be increased more than this limit due to the possibility of particle segregation. Particle breakage due to the additional densification was not noticed. By increasing both tapping number and additional densification process, the maximum density was increased by 3.59% (avg. 2.85%) in the JIS method and 4.31% (avg. 3.15%) in the simplified method. The increase in maximum density by the additional densification process and number of tapping is shown in Figures 3a and 3b for Japanese standard method and simplified method respectively.

Table 4. Maximum and minimum densities: MJ sand

	JIS (2000)	Simplified method	Air pluv. method
No. of tests	10	10	15
ρ_{max}, kN/m^3 (max)	14.77	14.88	15.18
ρ_{max}, kN/m^3 (Avg)	14.70	14.85	15.12
Stand. dev., kN/m^3 (Avg)	0.039	0.024	0.043
COV (%)	0.26	0.16	0.29

	JIS (2000)	Slurry-based method
No. of tests	10	2
ρ_{min}, kN/m^3 (min)	11.73	12.78
ρ_{min}, kN/m^3 (Avg)	11.78	12.82
Stand. dev., kN/m^3 (Avg)	0.026	0.049
COV (%)	0.22	0.38

Table 5. Maximum and minimum densities: HW sand

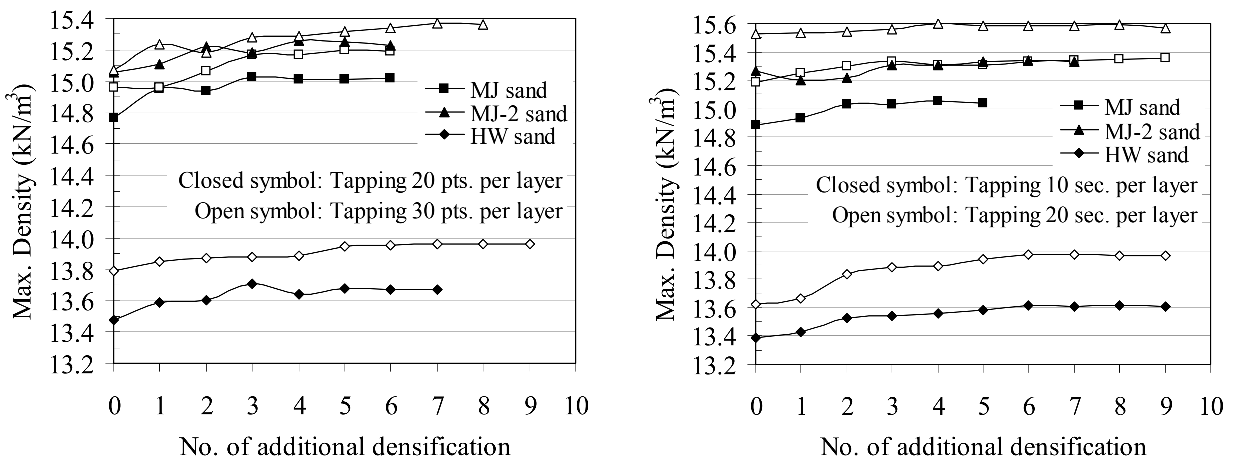
	JIS (2000)	Simplified method	Air pluv. method
No. of tests	10	10	10
ρ_{max}, kN/m^3 (max)	13.48	13.39	13.87
ρ_{max}, kN/m^3 (Avg)	13.43	13.34	13.83
Stand. dev., kN/m^3 (Avg)	0.031	0.045	0.042
COV (%)	0.23	0.34	0.31

	JIS (2000)	Slurry based method
No. of tests	10	2
ρ_{min}, kN/m^3 (min)	10.82	11.59
ρ_{min}, kN/m^3 (Avg)	10.86	11.62
Stand. dev., kN/m^3 (Avg)	0.024	0.046
COV (%)	0.22	0.39

Table 6. Maximum and minimum densities: MJ-2 sand

	ASTM (D4253-00)	JIS (2000)	Simplified method	Air pluv. method
No. of tests	2	10	10	10
ρ_{max}, kN/m^3 (max)	14.68	15.05	15.26	15.39
ρ_{max}, kN/m^3 (Avg)	14.66	15.02	15.17	15.34
Stand. dev., kN/m^3 (Avg)	0.034	0.032	0.067	0.020
COV (%)	0.23	0.21	0.44	0.13

	ASTM (D4254-00)	JIS (2000)	Slurry based method
No. of tests	2	10	2
ρ_{min}, kN/m^3 (min)	12.67	12.21	12.96
ρ_{min}, kN/m^3 (Avg)	12.72	12.25	12.99
Stand. dev., kN/m^3 (Avg)	0.048	0.045	0.033
COV (%)	0.37	0.37	0.25



(a) Japanese standard method (b) Simplified method

Fig. 3. Increase in maximum density by additional densification process.

5. Conclusion

1. The air pluviation method produced the highest maximum density among all sands, whereas the JIS method produced the lowest maximum density in the MJ and MJ-2 sand. The maximum differences among three methods except ASTM were 2.68% in MJ sand, 2.17% in the MJ-2 sand and 3.47% in HW-sand.
2. The JIS method produced the lower minimum density in all sands. The slurry-based method gave the minimum density of 8.23% higher than that of the JIS method.
3. The conventional ASTM method produced the lower maximum density and higher minimum density than the other methods on the sands.
4. By performing additional densification process, the maximum density was increased by 1.97% in the JIS method and by 2.52% in the simplified method. By increasing the number of tapping, the maximum density was also increased by 2.28% and by 2.06% respectively in each method. By the increase in the tapping number and the additional densification process, the maximum density was increased by 3.59% in the JIS method and by 4.31% in the simplified method.

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