Effectiveness of the Underwater Tamping Method for Compaction of Sandy Soils

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Abstract. The tamping method is a manual soil compaction technique, that involves the application of repetitive localized impacts using a rod to compact soils. Although the compaction of sandy soils in a moist state is widely used in laboratory and field conditions, the compaction of sandy soils in an underwater condition presents unique challenges. This paper presents the effectiveness of the tamping method when applied underwater, focusing on its effectiveness for soil densification. So, three compaction strategies—drop hammering at the optimum moisture content, drop hammering at an arbitrarily chosen moisture content (6%), and tamping underwater—were assessed in order to ascertain the efficiency of the underwater tamping method. Test results reveal that the tamping underwater method yields excellent densification in terms of the relative density of sandy soils. The minimum relative density achieved is 68% for small-scale laboratory compaction underwater with a compaction energy of 105 kN-m/m^3. The minimum relative density achieved is 44% by the method of drop hammering at the optimum moisture content at the same compaction energy. Compared to drop hammering in moist conditions, tamping underwater is found more efficient for the densification of sandy soils. However, the method of manual tamping underwater may not be feasible for large-scale compaction works, and hence, alternate methods with greater energy transfer capacity and broader coverage may be considered.

Keywords: Underwater Compaction, Rod Tamping, Relative Compaction, Relative Density, Compaction Energy.

1 Introduction

Sand compaction is an important activity at construction sites since it significantly affects the soil's behavior, stability, and ability to support load. Several methods can be used to densify sandy soils. Small-scale applications typically involve manual operations, while large-scale projects include heavy mechanical processes. Each method has some benefits and drawbacks that are taken into consideration before its selection for a particular situation. The most efficient ones for sandy soil compaction include dynamic, hydrodynamic, rapid impact, heavy vibratory plate, and drop hammering methods. For

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moisture-susceptible materials like sand, the choice of compaction method is very crucial [1]. While selecting the best technique, several factors including depth, compaction area, and environmental constraints come into play. In addition, layer thickness affects dry density after compaction, while capillarity and lubrication influence the shape of the compaction curve [2].

Sandy soil can be improved by up to 5.0 meters with rapid impact compaction [8]. It is cost-effective and time-efficient for densification of sandy soils with low silt and clay content [8]. Compared to clean sandy soil, silty sand requires a longer compaction time [9]. The dynamic method of compaction is effective in densification and requires less energy for sandy soils [10, 11]. The method of rolling and vibro-compaction are less effective at higher moisture content [12]. The water-sinking sand method also ensures high-quality compaction [13].

Although there are many soil compaction methods in field applications, the underwater tamping method is a soil compaction technique that has limited application in laboratory and small-scale construction. This method is important in the case where mechanical compaction techniques are either impractical or unavailable. Sometimes, the sand filling is to be done in small pits below the groundwater table where the conventional compaction system is not possible. In such cases, manual compaction is done with a tamping rod. But, the effectiveness of this type of compaction is not well-evaluated. This paper presents a study that attempts to evaluate the effectiveness of the underwater tamping method for sandy soils. The following sections present the methodology followed in this study and the results obtained.

2 Materials and Methods

2.1 Materials and Compaction Tools

Sandy soils from six locations in Bangladesh were collected for this study. The grain size distribution curves are shown in Fig. 1. The grain size analysis of these sands is conducted according to ASTM D422-63 standard [3]. The types of sand range from fine to coarse with fineness module of 1.15 to 2.28. Two types of compaction tools were used in this experimental work. One is a tamping rod of 10 mm diameter and 0.178 kg weight, and a tamping rod of 16 mm diameter and 2.45 kg weight for small-scale and large-scale tests respectively. Other compaction tools were a drop hammer of 0.385 kg and 12.2 kg weight for small-scale and large-scale tests respectively. The falling height was 30 cm for drop hammering and 20 cm for underwater tamping. The compaction tools and activities for small-scale compaction and large-scale compaction are shown in Fig. 2 and Fig. 3 respectively.

2.2 Methodology

The experimental program of the present investigation was divided into two stages. In the first stage, the compaction of sandy soils was performed in Proctor compaction molds, and in the second stage, the compaction was carried out in a large concrete chamber of 0.9 m diameter and 0.9 m height. The moisture content considered for this study was 6% (arbitrarily chosen) and the optimum moisture content at the standard Proctor compaction test as per ASTM D698-12 standard [4]. Low compaction energies such as 35, 70, and 105 kN-m/m^3 were arbitrarily selected for this study. The drop hammering in moist conditions was done using a hammer of weight 385 gm as shown in Fig. 2(a), and underwater tamping was done with a rod of 178 gm as shown in Fig. 2(c). Six types of sand were tested in the first stage to determine the effectiveness of the compaction methods for the small scale. On the other hand, in the second stage of the study, only Bhuapur sand is compacted to know the effectiveness of the compaction methods on a large scale. The compaction energy was not calculated because of complicacy. In this stage, the compaction of sand was done by a person who was in the compaction chamber. The evaluation of the energy transferred by the compression of the footsteps of the compaction personnel is complicated, so the compaction energy could not be reported. The number of tamping per layer in the underwater state was arbitrarily chosen as 100, 200, and 300 for large-scale compaction tests. Photographs of large-scale compactions are shown in Fig. 3.

In the first stage of the experimental works, the compaction of sand types was done in three equal layers. The soil samples were compacted in six equal layers for second stage of the experimental works. The dry density of compacted soils was determined from the total weight of dry sand compacted in the mold divided by the volume of the mold. In the second stage, the density of the top layer and the middle layer was tested at four points located at 90^0 to the center of the chamber, and the average was considered as the density of sand. ASTM D4914-08 standard [5] test method was followed for the determination of the density of compacted sand in the large chamber. Relative compaction (R_c) was calculated from equation (1), where, ρ_{d_sample} and ρ_{d_max} are respectively the dry density of the sample and the maximum dry obtained from the laboratory compaction test following ASTM D698-12 [4]. The relative density (D_r) was calculated from the equation (2), where e_{max} and e_{max} are respectively the maximum and minimum void ratios are determined as per ASTM standards [6,7].

$$R_c\ (\%) = \rho_{d\_sample}/\rho_{d\_max} \times 100 \quad (1)$$

$$D_r\ (\%) = (e_{max} - e)/(e_{max} - e_{min}) \times 100 \quad (2)$$

Sand compaction is an important activity at construction sites since it significantly affects the soil's behavior, stability, and ability to support load. Several methods can be used to densify sandy soils. Small-scale applications typically involve manual operations, while large-scale projects include heavy mechanical processes. Each method has some benefits and drawbacks that are taken into consideration before its selection for a particular situation. The most efficient ones for sandy soil compaction include dynamic, hydrodynamic, rapid impact, heavy vibratory plate, and drop hammering methods. For moisture-susceptible materials like sand, the choice of compaction method is very crucial [1]. While selecting the best technique, several factors including depth, compaction area, and environmental constraints come into play. In addition, layer thickness affects dry density after compaction, while capillarity and lubrication influence the shape of the compaction curve [2].

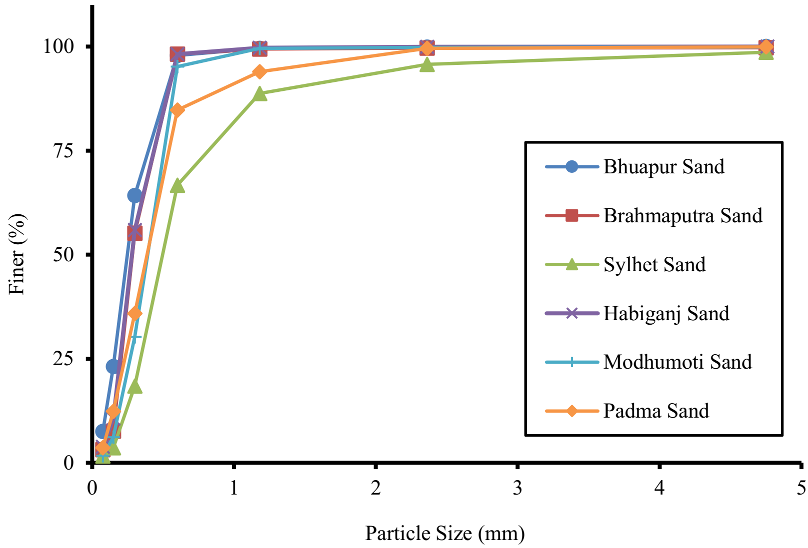

Fig. 1. Particle size distribution curves of different types of sands used in the present study.

(a) Drop hammer (385 gm)

(b) Compaction by drop hammering

(c) Underwater tamping rod (178 gm)

(d) Compaction by underwater tamping

Fig. 2. Compaction tools and activities in the first stage of the study.

a) Drop hammering on a large scale

b) Underwater tamping on a large scale

Fig. 3. Compaction tools and activities in the second stage of the study.

3 Results and Discussions

3.1 Effect of Compaction Energy

Relative compaction, the ratio of the dry density of the sample to the maximum dry density of the sand for drop hammering in 6% moisture content and optimum moisture content (OMC) is presented in Fig. 4 and Fig. 5 respectively. It can be seen that the maximum relative compaction that has been attained by drop hammering with the maximum energy of 105 kN-m/m^3 is 94%. The effect of compaction energy on the relative compaction and relative density of various sands obtained from drop hammering at 6% moisture content and optimum moisture content are shown respectively in Fig. 6 and Fig. 7. It shows that the relative density of sands achieved from the drop hammering method is below 51%. The maximum relative compaction and relative density obtained are 96% and 57% respectively. The use of the drop hammering method cannot ensure the dense condition of the sand deposit for the range of compaction energy used in the present study. It is evident that the relative compaction and the relative density both increase with increasing compaction energy. So, a compacted sandy deposit can be produced with higher compaction efforts.

On the other hand, the relative compaction and the relative density of compacted sands for different compaction energy using the underwater tamping method are presented in Fig. 8 and Fig. 9 respectively. The relative compaction of sands attained from the underwater tamping method is more than 95% for compaction energy of 35 kN-m/m^3 to 105 kN-m/m^3 which is satisfactory according to most of the construction specifications in Bangladesh. From Fig. 9, it can be seen that the relative density of sand obtained in the underwater tamping method is more than 60% for most of the methods. For Bhuapur sand, the relative density is more than 80%. Thus, a sand of dense state can be prepared in the laboratory using the underwater tamping method. The energy used in this study is 105 kN-m/m^3 which is as low as 17.5% of the standard Proctor compaction energy.

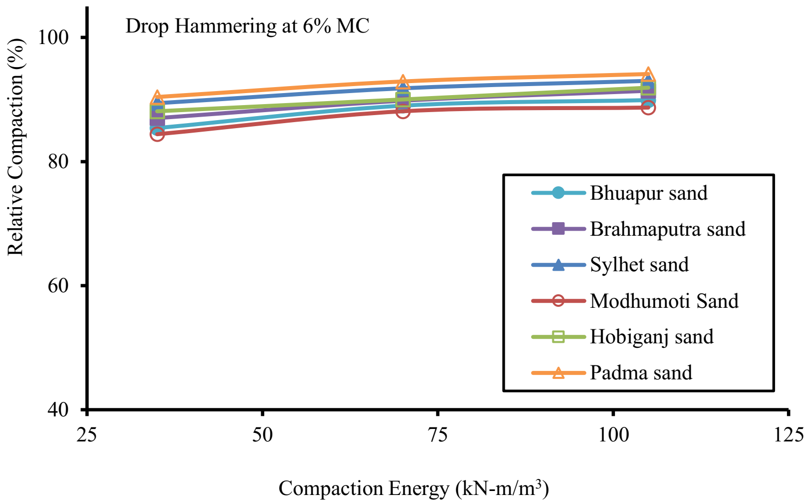

Fig. 4. Effect of compaction energy on the relative compaction of various types of sand for drop hammering method (6% moisture content).

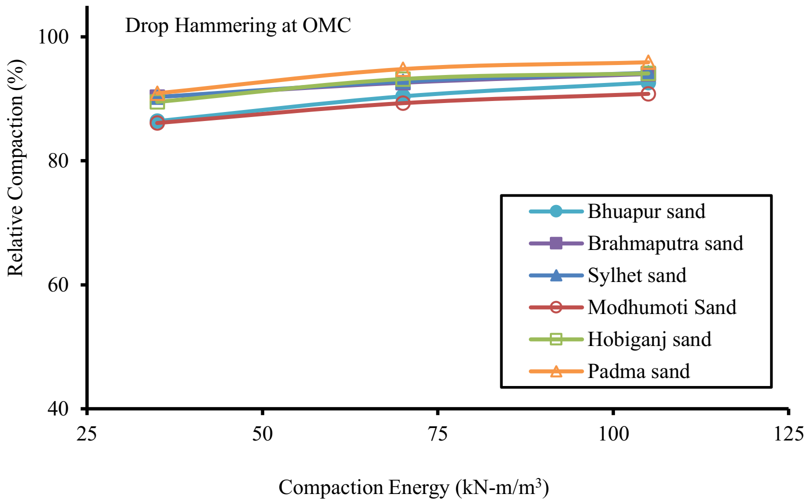

Fig. 5. Effect of compaction energy on the relative compaction of various types of sand for drop hammering method (moisture content = OMC).

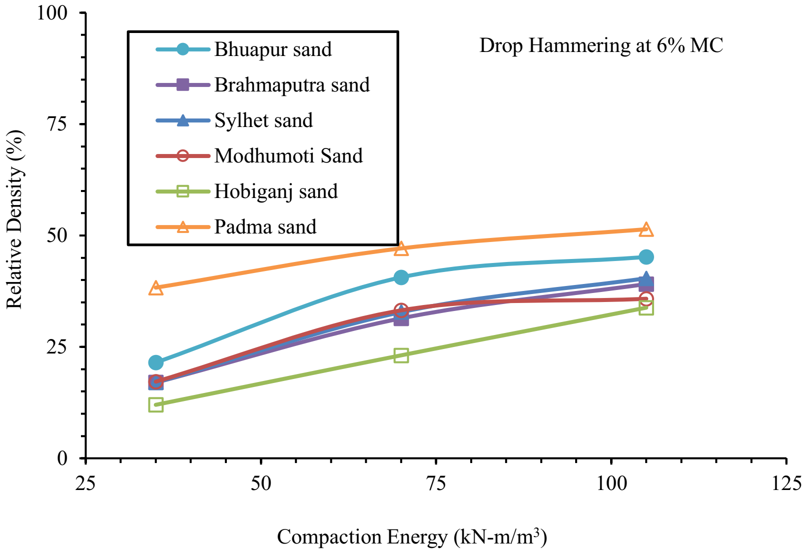

Fig. 6. Effect of compaction energy on the relative density of various types of sand for drop hammering method (6% moisture content).

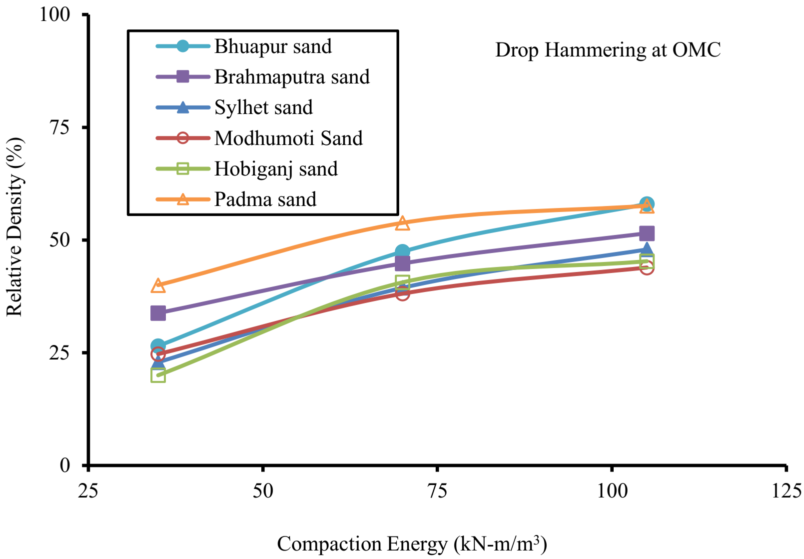

Fig. 7. Effect of compaction energy on the relative density of various types of sand for drop hammering method (moisture content = OMC).

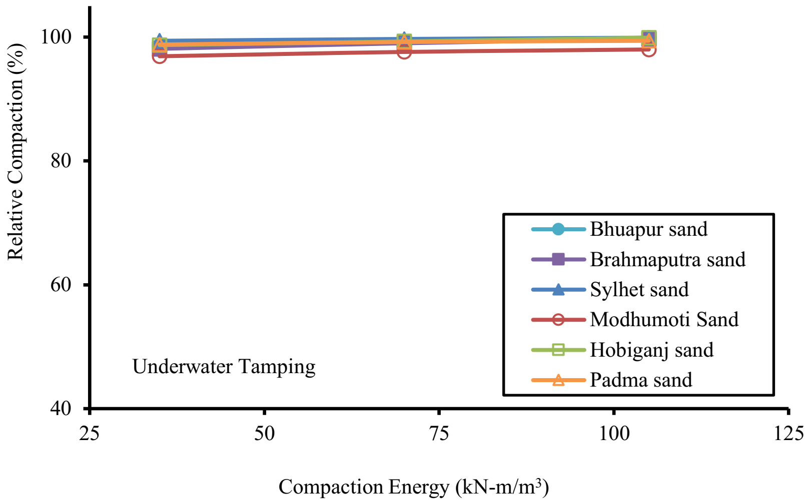

Fig. 8. Effect of compaction energy on the relative compaction of various sands by underwater tamping method.

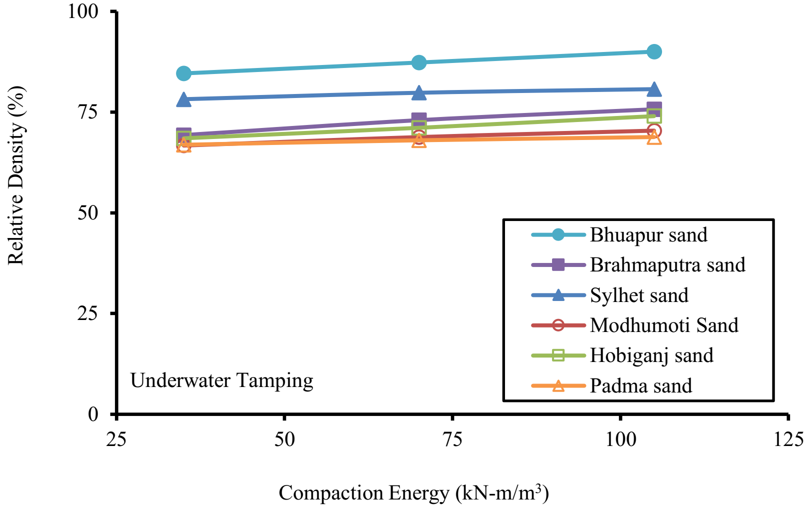

Fig. 9. Effect of compaction energy on the relative density of various sands by underwater tamping method.

3.2 Effect of Compaction Methods

The effect of compaction methods on the relative compaction of small-scale compacted samples is shown in Fig. 10 to Fig. 12, and the effect of compaction methods on the relative density is shown in Fig. 13 to Fig. 15. The compaction energies used for these samples were very small compared to standard Proctor compaction energy. It can be seen that underwater tamping is the most efficient for compaction using low compaction energy as used in the present study. It is due to less bulging of sand under the water table. Another source of higher compatibility is the lower resistance of soil to move laterally under water conditions, and hence dense sand can be obtained with less effort. Because of higher compaction at low compaction efforts, the chance of increasing density by increasing compaction energy is small.

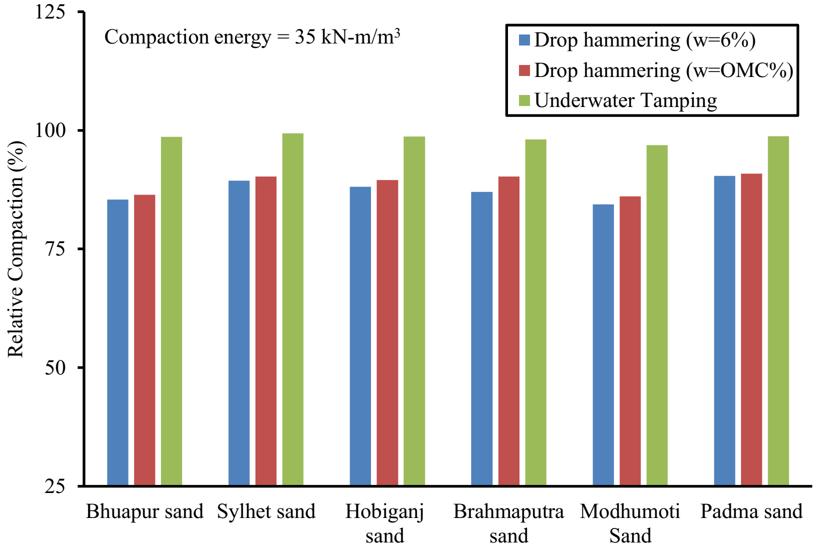

Fig. 10. Effect of compaction methods on the relative compaction of various types of sand (compaction energy = 35 kN-m/m^3).

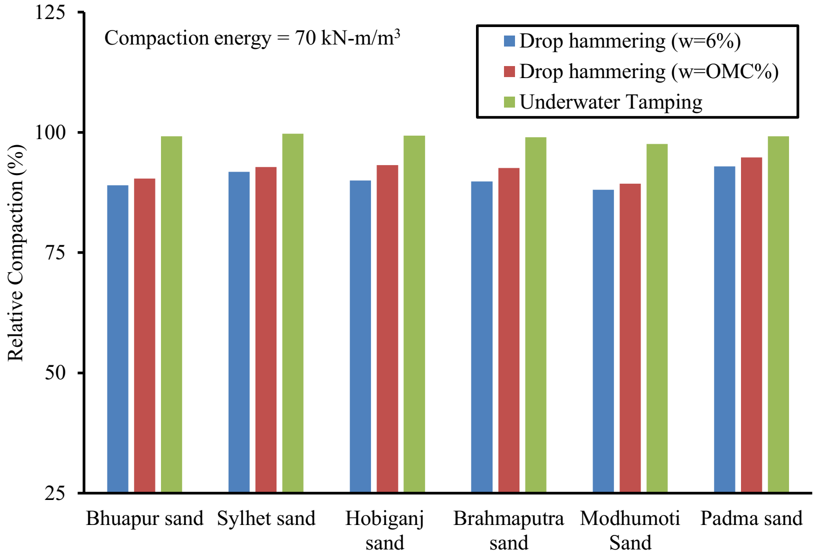

Fig. 11. Effect of compaction methods on the relative compaction of various types of sand (compaction energy = 70 kN-m/m^3).

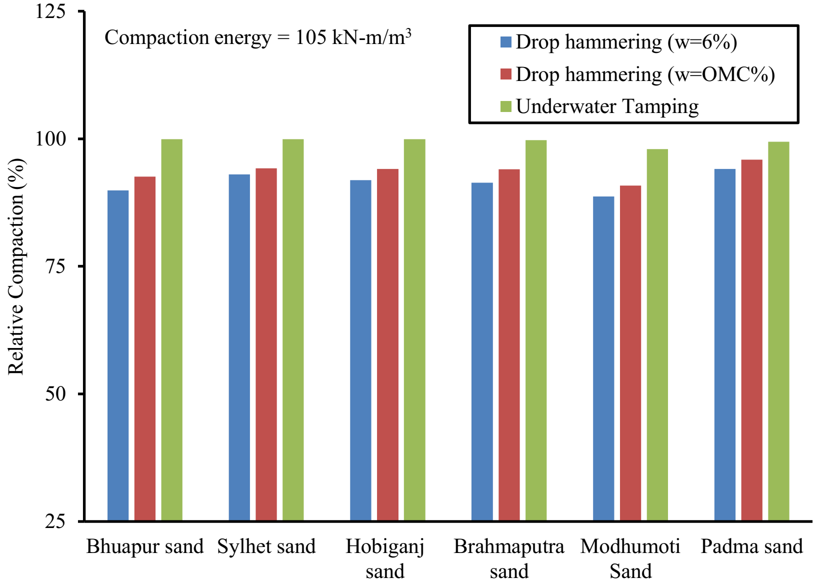

Fig. 12. Effect of compaction methods on the relative compaction of various types of sand (compaction energy = 105 kN-m/m^3).

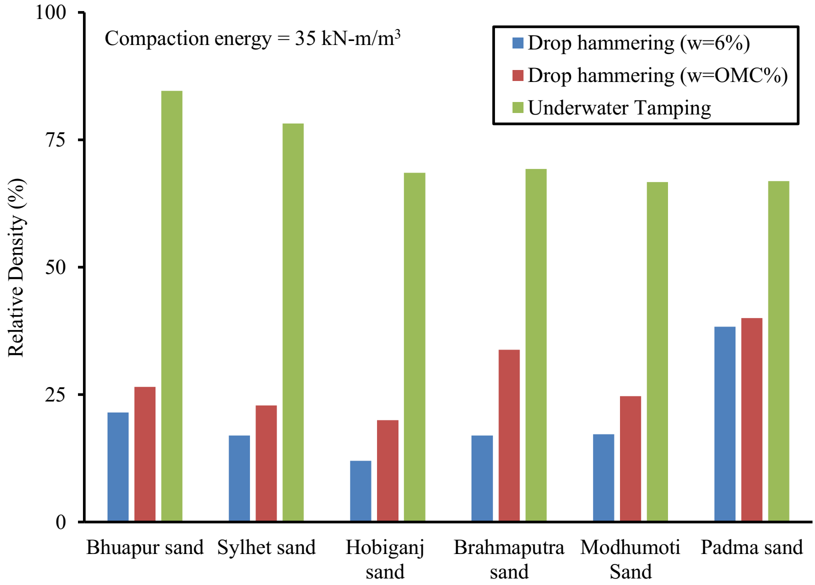

Fig. 13. Effect of compaction methods on the relative density of various types of sand (compaction energy = 35 kN-m/m^3).

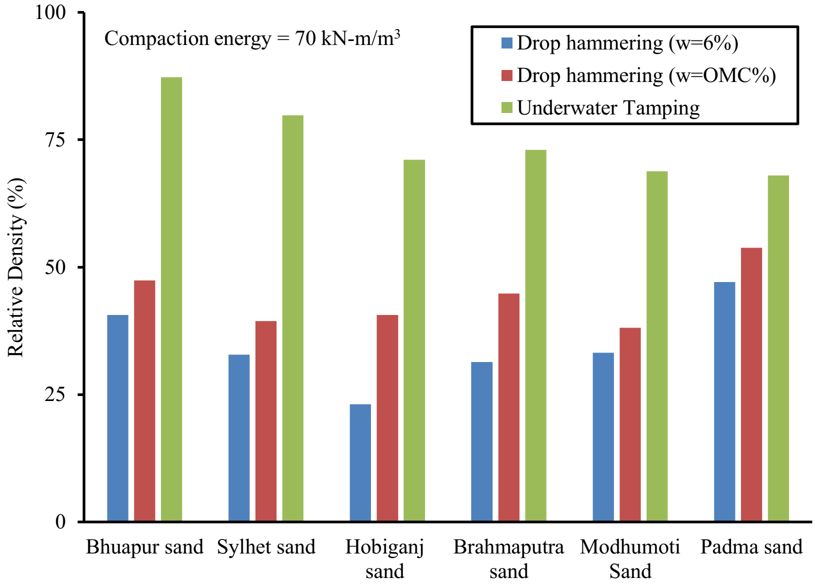

Fig. 14. Effect of compaction methods on the relative density of various types of sand (compaction energy = 70 kN-m/m^3).

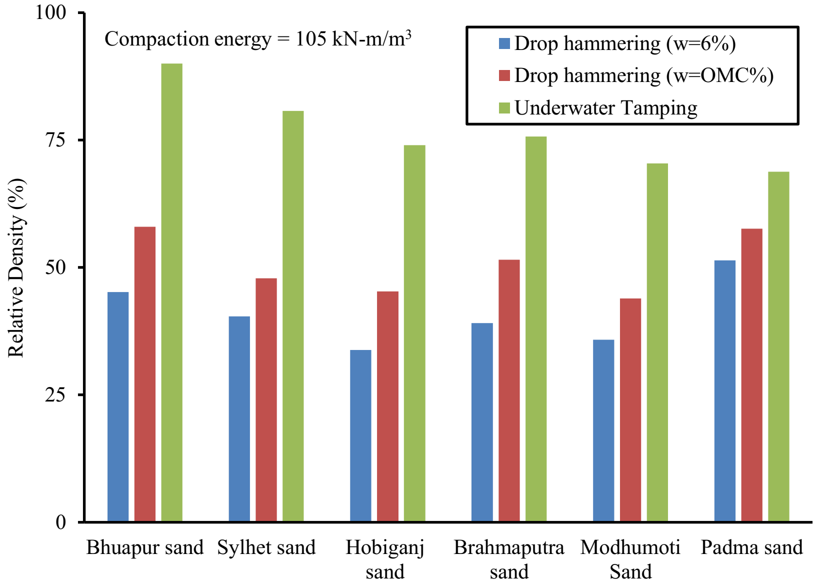

Fig. 15. Effect of compaction methods on the relative density of various types of sand (compaction energy = 105 kN-m/m^3).

3.3 Large-scale Compaction Test Results

A total of nine large-scale compaction tests were conducted in a large concrete chamber. The sand used for these compaction tests is Bhuapur sand. Compaction energies were 35, 70, and 105 kN-m/m^3 for the drop hammering method and 5, 10, and 15 kN-m/m^3 for the underwater tamping method. The additional compaction effort was the foot pressure of the compaction personnel. The compaction energy for the foot pressure of the compaction person is not determined. The resulting relative densities obtained from these tests are given in Table 1. The results indicate that the relative density achieved using the drop hammering method is 48% for compaction energy of 35 N-m/m^3 and the relative density is 78% for compaction energy of 105 kN-m/m^3 when the moisture content of sandy soils is 6%. While, with the same compaction energy, relative densities of 73.7% to 88.9% can be achieved from the same soil and the same compaction technique if the moisture content is equal to the optimum moisture content. The compaction test results of the underwater tamping method are excellent considering the density of soils. It can be seen that a relative density of 89.4% can be achieved with the minimum compaction energy (5 kN-m/m^3) using the underwater tamping method. The relative density observed in the large-scale test is higher for all the cases of small-scale tests. It is the effect of the foot pressure of the person compacting soil during compaction.

Table 1. Relative densities obtained from the large-scale tests using Bhuapur sand compacted underwater using a tamping rod and in moist conditions using a drop hammer.

Methods of Compaction	**Moisture content**	**Compaction Energy (kN-m/m^3)**	**No. of Tamping Per Layer**	**Relative Density, D_r (%)**
Drop hammering	6.0%	35	-	48.0
		70	-	56.4
		105	-	78.2
Drop hammering	OMC	35	-	73.7
		70	-	86.0
		105	-	88.9
Underwater Tamping	Saturated Soil	-	100	89.4
		-	200	89.5
		-	300	89.9

4 Conclusions

Based on test results, the following conclusions can be drawn:

1. The underwater tamping method is the most suitable method for sandy soils, especially when the use of compaction energy is very low. About 89% relative density of sandy soil has been achieved using compaction energy of 35 kN-m/m^3 which is about 6% of standard proctor compaction energy.
2. In the underwater tamping method of compaction of sands, a very small amount of compaction energy (35 kN-m/m^3) is necessary to densify the sand. So, application of further compaction energy has less impact on further densification of sands in underwater conditions compared to drop hammering methods under moist conditions.
3. The drop hammer method of compaction at optimum moisture content is found inefficient in making dense sand fill at low compaction energy. So, it is necessary to use high compaction energy for this method of compaction in making a dense sand filling.
4. For the range of compaction energy utilized in this study, the relative density of sands achieved was between 48% and 78% using the drop hammering compaction technique at 6% moisture content. In contrast, the relative density was obtained between 74% and 89% for drop hammer compaction at the optimum moisture content and between 89% and 90% for the underwater tamping method of compaction.

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