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Experimental study of the effect of holes number and arrangement of lattice pounder on offshore dynamic compaction

M.H. Taghizadeh Valdi[1], M.R. Atrechian[*2] , A. Jafary Shalkoohy[3], S.A. Hosseini[1]

[1]Department of Civil Engineering, Isfahan (Khorasgan) Branch, Islamic Azad University, Isfahan, Iran
[2]Department of Civil Engineering, Zanjan Branch, Islamic Azad University, Zanjan, Iran
[3]Department of Civil Engineering, Bandar Anzali Branch, Islamic Azad University, Bandar Anzali, Iran

ABSTRACT: In offshore dynamic compaction, the water effect on the deterioration of the pounder impact velocity on seabed and the crater depth formed in the soil is always a major challenge. In this paper, the water entry problem of lattice pounders of 9, 16, and 25 holes, with 3x3, 4x4, and 5x5 matrix arrangements respectively, the effect of the number, dimensions and arrangement of the pounder holes, on the impact velocity with simulated soil of the seabed and the crater depth formed in it was studied experimentally. The results showed that the impact velocity of the lattice pounders depends on the holes area, and the crater depth formed in the soil, the amount of energy transferred from the pounder to the soil and the improvement radius and depth of soil depend on the area of the pounder's lattice web. Therefore, in dynamic compaction of the seabed, increasing the pounder weight without reticulating it cannot considered as a suitable solution to increase the impact velocity on seabed and the effective factor on soil settlement and compaction. Also increasing the pounder weight and its drop height over the optimum drop height lead to increasing the operating costs, and it requires the use of large barges and long cranes with a high load capacity.

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1. INTRODUCTION

The first application of soil improvement on the seabed goes back to the 1970. Louis Menard carried out the first offshore dynamic compaction project in 1973 as part of the construction of Brest naval Port's prefabricated dry dock in France [1]. In this project a specially designed 11 ton pounder was used to compact about 3 m of loose alluvium seabed over an area of 4,500 m² [25-]. In 1975, offshore dynamic compaction was used at Pointe Noire in Gabon to improve the passive resistance of loose sand in front of a cellular sheet piled wall. The specially designed pounder used in this project weighed 12 tons. Prior to ground improvement a 0.4 m thick blanket of gravelly sand was placed over the seabed, located 13.5 m below sea level. Generally, in this 14,000 m² project two phases of dynamic compaction with compaction energy intensity of 240 tm/m² were applied to provide an allowable bearing capacity of 400 kPa. In 1975, at Udevalla, Sweden, offshore dynamic was applied for the treatment of a granite rock fill that was placed below the prefabricated caissons. The rock size was up to 1 m in diameter, the top of the fill was 12 m below sea level, and its thickness was variable from 17 to 20 m. Due to the size of the rock fill, dynamic compaction was performed by using a 40 ton pounder that was dropped from 40 m using the Menard's Mega Machine [6]. In 1977, a 32 tons pounder was used to compact a 5 m thick layer of silty sand and a 1.5 to 2 m thick rock fill blanket at the depth of 10 m below seawater level to mitigate the risk of liquefaction of a breakwater foundation at Kuwait Naval Base. Marine ground improvement was carried out over an area of approximately 36,000 m² [5,7]. In 1977, offshore dynamic compaction was applied for the treatment of seabed at Sfax Fishing Quay in Tunisia. In this project water depth was 1 m, and the seabed was composed of 5 m of very soft clay followed by 2 m of silty sand and 3 m of denser clayey sand, and firm clay. Dynamic compaction was performed using a 17 ton pounder with a square grid spacing of 2 m. Compaction was carried out in 3 to 5 phases with 2 to 10 blows per print [5,8]. In 1979, dynamic compaction was carried over an area of 13800 m² prior to placement of the prefabricated sections of a dry dock in Lagos Pier in Nigeria. Initially, the seabed was excavated to -15 m RL (reduced level), and backfilled with 1 m of rock fill. Soil improvement was carried out using a 40 ton pounder with the intention of treating 15 m of soil. Up to 5 passes of dynamic compaction were applied in some locations [5]. In 1980, a desalination plant was assembled in Japan, towed to Yanbu in Saudi Arabia, and sunk on a seabed foundation prepared by dynamic compaction. The seabed was composed of 8 m of loose silty sand, with the upper 4 m being very heterogeneous. Hence, the top 4 m of seabed was removed, and replaced by crushed coral, and dynamic compaction was applied using a 17 ton pounder that was dropped on a square grid with 8 m spacing. The number of blows per print in the compaction phases varied from 12 to 10. In 2010, dynamic compaction

*Corresponding author's email: atrechian@iauz.ac.ir

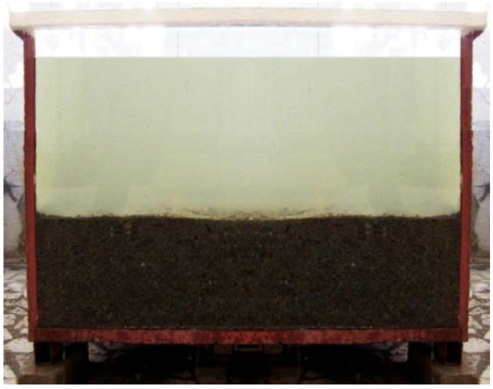

Fig 1. Saturated soil and water height above it

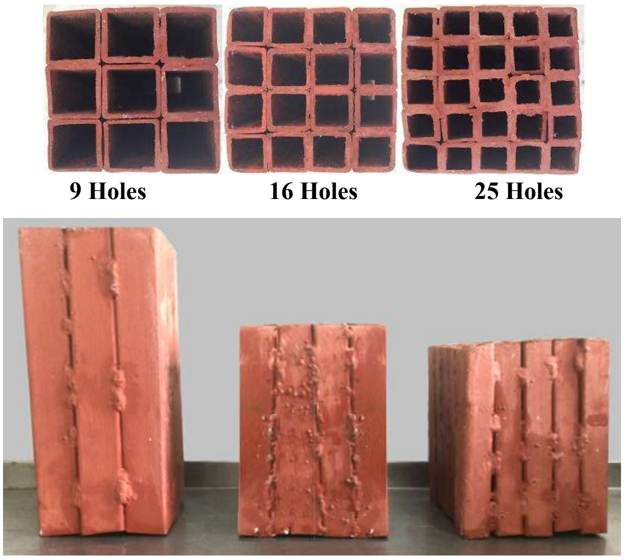

Fig 2. Lattice pounders with matrix arrangement

was used to improve the seabed soil in Southeast Asia. A lattice pounder with a base size of 1.7x1.7 m and weighing 38.5 tons was fabricated. The special shape of this pounder allowed minimum water resistance during the pounder's drop and penetration in the seawater. The drop height during the trial was set to 5 m above seabed level. Records of the crane's winch speed during the works indicate that the maximum drop speeds were in the range of 430 m/min. This speed is equivalent to a free fall with a drop height of 2.6 m (in air) and verifies the original assumption that much of the drops' kinematic energies would have been lost to water resistance. In the implemented researches, in order to reduce the effect of water on the depreciation of pounder collision velocity with the seabed, the lattice pounder have been used, but the number and dimensions of holes and their area, which must be proportional to the size and area of pounder and its lattice web, are less studied. In this paper, the arrival of lattice pounders with 9, 16 and 25 holes with a matrix arrangement 3x3, 4x4 and 5x5 in water and the effect of the number, dimensions and arrangement of the pounder holes on the collision velocity with of the seabed simulated soil and the depth of the created hole in it are studied experimentally.

2. MATERIALS AND METHODS

As shown in Fig 1, a cube-shaped test tank with dimensions of 100x100x80 cm is designed so that the effect of the walls on results is negligible. The side walls and floor of the tank are made of a 2 mm double-side welded steel plate and the forehead is made of 10 mm glass. In order to ensure that there is no leakage of water outside the tank, the welding spots of the steel plates and the bonding of the glass is adequately covered with sealing glue, and on the left side of the tank, there is a valve for emptying the water inside the tank when necessary. In order to absorb the waves due to the collision of pounder with the soil surface by tank walls, and its failure to return it to the computational domain after collision with side boundaries, the tank walls are covered with polystyrene sheets with thickness of 2 cm. Then the appropriate amount of poor-grained silty sand prepared from the Caspian seabed in Anzali port in north of Iran, so that its specifications are shown in Table 1. The soil test is poured in the test tank and will be compacted until it reaches a thickness of 30 cm and the density 40%. Because the seabed due to sedimentation and consolidation of sediments by waves and long-term loading caused by the weight of the water on it has relative density. Then the test tank will be slowly filled with water up to 40 cm above the soil surface, so that the initial soil density does not change. After that, the lattice pounders are released from a height of 1 m above the free water surface and their movement in the water depth from the instant of contact with the free water surface until the moment of contact with the soil surface is recorded by the high-speed camera. After the collision of pounder with the soil surface, the crater depth formed after each impact is measured.

In Fig 2, the geometric shape of the pounders is shown. As can be seen, three types of lattice pounders with variable number of holes including 9, 16 and 25 holes are arranged in a matrix arrangement of, 3x3, 4x4 and 5x5 respectively for dynamic compaction of simulated soil from seabed in a laboratory environment. Pounder's weight is considered to be 3.85 kg. The experimental observations include the pounder's movement in water depth and the collision with the soil surface of the model bed, which creates a crater in it. The pounder's release position is adjusted so that it impacts the soil in a specific point after each release. After each impact, the amount of penetration of the pounder in the soil, and in other word the crater depth is measured and recorded. The dynamic compaction operation continues until the pounder penetration in the soil stops, and after the crater depth did not change significantly due to the collision, the amount of soil settlement in that area is measured. Then, the effect of repeated pounder blows on the compaction of the colored layers of the soil and the reduction of the thickness of each layer is investigated then the depth of soil improvement is determined by the impact of the blows. The geometric characteristics of the lattice pounders are in Table 2.

3. RESULTS AND DISCUSSION

Fig 3 shows the effect of holes number and arrangement of the lattice pounders on crater depth after each impact. As can be seen, the 25 holes lattice pounder which has a more web area than other lattice pounders, lead to create a highest crater depth in the soil depth after each impact. In contrast,

Table 1. Geotechnical properties of Anzali sand

G_s	e_{max}	e_{min}	$\gamma_{d_{min}}$ (kN/m^3)	$\gamma_{d_{max}}$ (kN/m^3)	C_c	C_u	D_{max} (mm)	D_{50} (mm)	USCS
2.67	0.71	0.57	15.6	16.9	1.2	2.4	1.18	0.21	SP-SM

Table 2. Geometric properties of lattice pounders

Number of holes	Holes arrangement	Pounder dimensions (cm)	Hole dimensions (cm)	Wall thickness (cm)	Holes spacing (cm)	Holes area (cm^2)	Lattice web area (cm^2)	Wall area of holes (cm^2)	Moment of inertia (cm^4)
9	3x3	10x10x22.5	2.83	0.25	0.5	75.25	24.75	2295	19
16	4x4	10x10x16.5	2	0.25	0.5	64	36	2112	24
25	5x5	10x10x14.5	1.5	0.25	0.5	56.25	43.75	2175	29.16

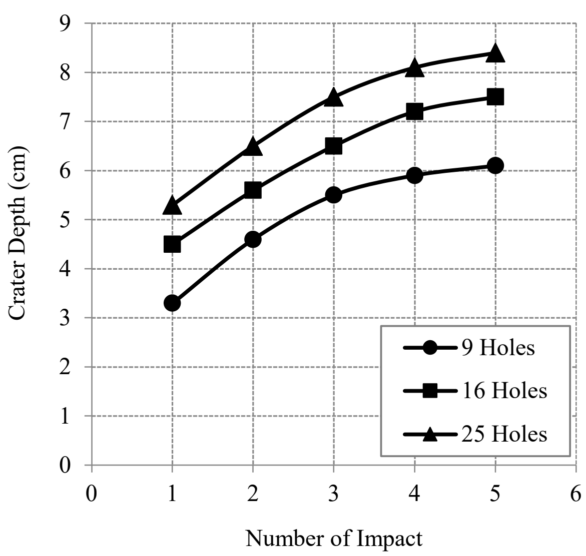

Fig 3. The effect of holes number and arrangement of the lattice pounders on crater depth after each impact

the 9 holes lattice pounder which has minimum web area creates a lowest crater depth in the soil after each impact. Therefore, it can be concluded that the impact velocity of the lattice pounders depends on their holes area, and the crater depth formed in the soil, amount of energy transferred from pounder to the soil and its improvement radius and depth depends on the web area of lattice pounders. Hence, with increasing the pounder's holes area, the pounder's velocity depreciation will decrease while moving in the water depth and as a result, the pounder impacts the seabed with high velocity. On the other hand, increasing the web area of lattice pounders leads to transferring the more energy from pounder to the soil and increasing its improvement radius and depth. As a result, the amount of pounder penetration in the soil will be increased and creates a deeper cavity. Therefore, in designing the lattice pounders for the dynamic compaction of the seabed, the number, dimensions and area of holes in lattice pounders should be proportionate with their dimensions and lattice web area. So that in addition to having the least velocity depreciation while moving in the water depth and reaching the highest velocity at the moment of collision with the seabed, and lead to a maximum improvement radius and depth of soil.

4. CONCLUSIONS

In this paper, the water entry problem of lattice pounders with 9, 16 and 25 holes and matrix arrangement of 3x3, 4x4 and 5x5 respectively was simulated experimentally, and the effect of the number, dimensions and arrangement of the pounder holes on the impact velocity with seabed and also the crater depth formed in soil were studied. The results showed that impact velocity of the lattice pounders depends on the area of the holes, and crater depth formed in the soil, amount of energy transferred from the pounder to the soil and also its improvement radius and depth depend on the web area of the lattice pounders. Hence, the larger the pounders holes and their area would be, the deterioration of the pounder's velocity decreases while moving in the depths of the water, and the pounder will impact the surface of the seabed faster, And the larger the web area of the lattice pounders would be, the penetration amount in the soil is greater and the cavity is deeper.

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