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Development and improvement effectiveness of sand compaction pile method as a countermeasure against liquefaction

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Abstract

The sand compaction pile (SCP) method was developed in Japan to improve soft grounds. One of the major features of the SCP method is that it can be applied to all soil types found in Japan, from sandy to clayey soils; and therefore, it has been widely used for the improvement of soft grounds. Recently, the SCP method has been mainly adopted as a countermeasure against liquefaction, and its effectiveness in preventing liquefaction has been confirmed through past large earthquakes. This paper provides an outline of the conventional SCP method, including its principle, history, equipment, and implementation, and also describes other methods derived from the SCP method as liquefaction countermeasures. Furthermore, several examples are reported to confirm the effectiveness of the methods through past large earthquakes.

Keywords: Ground improvement; Sand compaction pile; Countermeasure against liquefaction

1. Introduction

The sand compaction pile method (hereinafter abbreviated as the SCP method) is a method for improving soft grounds by means of installing well-compacted sand piles in the ground. It combines such fundamental principles for ground improvement as densification and drainage. It can be applied to all types of soil found in Japan, from sandy to clayey soils, by commonly using a single piece of equipment; therefore, it has been widely used for the improvement of soft grounds. In sandy grounds, the SCP method is mainly used as a countermeasure against liquefaction, and its effectiveness in preventing liquefaction has been confirmed through past large earthquakes, showing that this method is one of the most reliable ground improvement methods in Japan.

This paper describes the principle, the history, and the equipment of the conventional SCP method as well as outlines two other methods derived from the SCP method in accordance with the needs of the times as liquefaction countermeasures including the procedure, the equipment, and the material used for each method. Some cases are also shown that demonstrate the difference between an unimproved ground and a ground improved by the SCP method based on the degree of damage brought about by past large earthquakes.

2. Outline of SCP method

2.1. Principle and purpose of the SCP method

The SCP method is effective in improving the performance of all the types of ground for different reasons. The reasons for such effectiveness in three representative

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soil types, i.e., sandy grounds, clayey grounds and soft clay deposits which is typically formed at offshore sites, are described. The principle of the SCP method for clayey grounds is based on the theory for composite grounds proposed by Murayama (1957). Composite grounds consist of soft cohesive grounds and compacted sand piles formed therein; the composite ground formed has high shear strength and drainage capability owing to the presence of the sand piles. Through the formation of these compacted sand piles, the bearing capacity of the ground can be increased due to "replacement effect" and "stress concentration effect". "Stress concentration" means that external load is concentrated mainly on the sand piles, as shown in Fig. 1(a). Furthermore, by including "drainage effect" (see Fig. 1(a)), an increase in the stiffness of the whole ground as well as a decrease in lateral spreading and in consolidation settlement can be expected.

On the other hand, the principle of the SCP method for sandy grounds is primarily to decrease the void ratio and to densify the ground as a result of the sand pile installation, as shown in Fig. 1(b). Accordingly, the purpose of the SCP method is to increase the bearing capacity, to decrease the compression settlement, to prevent the occurrence of liquefaction, and to increase horizontal resistance. For sandy grounds, Ogawa and Ishido (1965) suggested a practical design procedure related to the increase in density due to the installation of sand piles.

Conversely, for soft clay deposits which are typically encountered in offshore works, thicker sand piles are installed into the clay at the sea bottom, as shown in Fig. 1(c). "Forced replacement" is the major principle for the improvement of offshore works, rather than the formation of "composite ground" where the sand piles replace the cohesive soils. In such cases, the objectives of the improvement are to increase the bearing capacity, to reduce the consolidation settlement, and to increase the horizontal resistance.

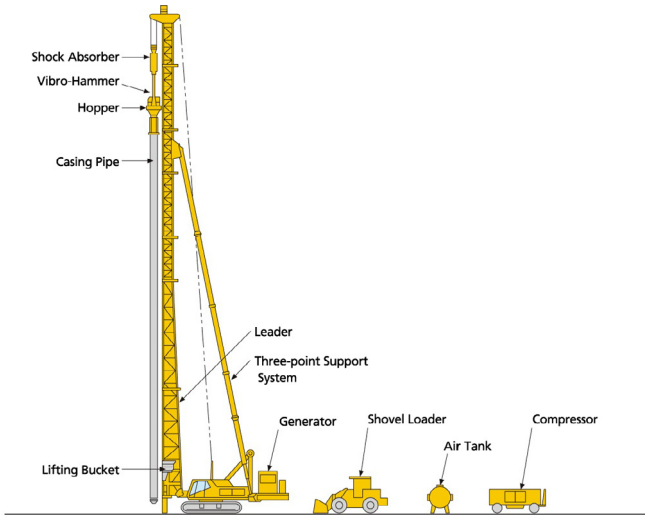

Fig. 2. Vibratory SCP equipment.

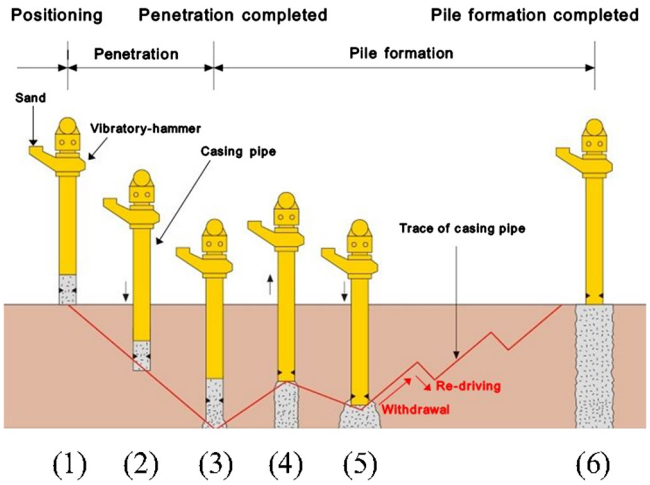

Fig. 3. Installation procedure for vibratory SCP method.

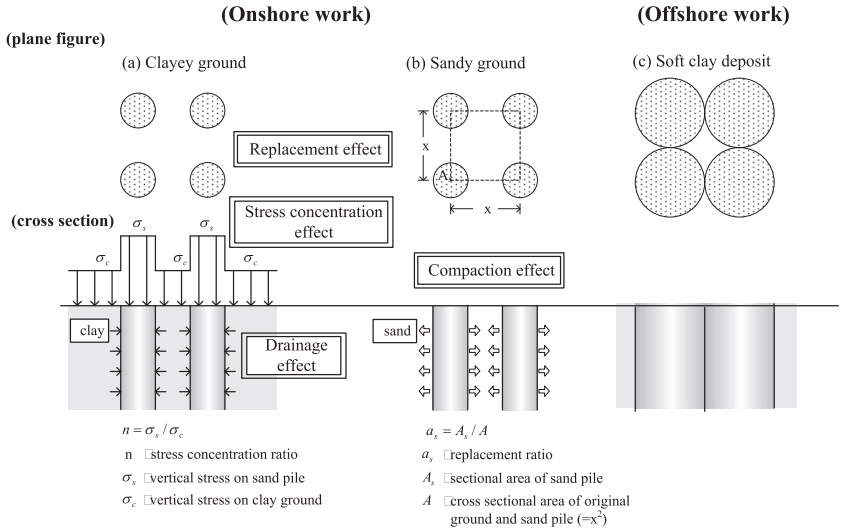

Fig. 1. Concept for installation of compacted sand piles.