A Review Study on Sand Compaction Piles in Cohesive Soils and as a Liquefaction Resistance Technique

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Abstract - The paper presents a detailed review of the state-of-the-art ground improvement technique namely sand compaction piles. The technique being originated in Japan has flourished around the globe for its efficient characteristics to act as a reinforcing member when it is installed in clays and is recognized as one of the best methods to prevent liquefaction. Known for its larger bandwidth of advantages, articles summarising the literature contribution on the technique are found to be very limited. Therefore, an attempt has been made to review the noteworthy literature that provides valuable information on the subject. An overview of the literature present on sand compaction piles installed in cohesive soils targeted to meet various demands like increasing bearing capacity, settlement, etc., and the technique’s efficiency in mitigating liquefaction associated problems are discussed.

Keywords - sand compaction pile, cohesive soils, liquefaction, review study, bearing capacity

1. Introduction
Sand compaction pile (SCP), a pile made of sand, that is compacted upon installation is often used as a pile in reclaimed lands, loose cohesionless stratum, soft soils (clay), to prevent liquefaction. The principle and working mechanism of the SCP technique varies in each and every mentioned soil stratum as mentioned above, including its performance attributes [1],[2]. To name a few, the SCP acts as a reinforcing member and drainage element when installed in cohesive soils [3]. It acts as an effective technique to withstand the aftermath effects of liquefaction in Japan, where the highest probability of the world’s earthquakes often occurs [4]. The present paper deals with the summarization of noteworthy literature available on the SCP technique that is implemented in soft soils and to prevent earthquake-induced liquefaction [5].

2. SCP Improved Cohesive Soils
Sand compaction piles have been in use for more than 5 decades since 1956 to improve the weak and dredged soils [6]. Many of the earlier successfully implemented projects such as offshore land reclamation projects (e.g., International Airports such as Kansai, New Kitakyusha, Kobe, and Chubu, Japan; Chep Lap Kok Airport, Hong Kong; Incheon Airport, South Korea), onshore structures like oil storage facilities in refineries, coastline structures such as port and harbor facilities, etc., stands as an evidence for the same [7]. The SCPs often provide a cost-effective and fast solution to improve the loose sandy deposits and soft clayey soils for the large-scale land reclamation work from the sea [8]. The intention of employing the SCP treatment in cohesive soils is to enhance the load-carrying capacity and reduce the probable settlement [9],[10],[11]. The sand piles in soft soils act as a stiff element (drains) and also accelerate the drainage movement by providing a drainage path that eventually results in decreased time required for primary consolidation of saturated clayey grounds [12],[13].

The SCPs in clays play a similar role as that of the preloading technique in clays which is often aimed to reduce the excessive primary settlement of the improved ground well before the execution of the superstructure [14],[15],[16]. The performance of the SCPs in soft soils evaluated before and after the treatment has been well documented in the earlier studies as presented in Table 1. The table includes some of the available literature on the SCPs in clays focusing mainly on the laboratory and field case studies [17]. It is evident from the table that the consolidation and deformation behaviour, pressure-settlement response, effects of SCP installation in the clay deposit with and without smear, shear strength, load transfer, bearing capacity, and settlement characteristics of these composite systems are addressed extensively in the literature [18].

| Literature | Description |
|------------|-------------|
| [21]       | Mechanical response of soft cohesive deposit improved with SCP |
| [19]       | Compressibility characteristics of cohesive soils reinforced by SCP |
| [23]       | Bearing capacity characteristics of soft ground improved by SCP with low ARR |

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M.G. Sumithra et al.(eds.). Advances in Computing, Communication, Automation and Biomedical Technology, https://doi.org/10.46532/978-81-950008-1-4_078
3. SCPs For Liquefaction Resistance

The SCP method is implemented in sands and silty grounds to address the following applications: increase of bearing capacity, reduction of total and differential settlements, preventing stability failure of structures, and reduction of liquefaction hazards [19],[20],[21],[22]. Wider use of the SCPs as liquefaction countermeasures for different structures started in the aftermath of the Niigata Earthquake in 1964. The efficiency of the SCP method as the liquefaction countermeasure was identified when a foundation of the tank constructed on the SCP treated ground prevented the liquefaction during a massive earthquake that occurred near the coast of Miyagi Prefecture in 1978, Japan [23],[24],[25],[26]. Followed by which a survey undertaken on the buildings that showed that these buildings stood firmly on the SCP improved grounds [27],[28],[29],[30]. This stated that the implementation of the method successfully served as an effective countermeasure against the liquefaction. More details on the classic success story of the SCP method can be obtained from the case studies related to the Nihonkai–Chubu Earthquake in 1983, Japan [31],[32].

Later on, extensive studies have been carried out to identify the possible reasons why the SCP improvement averted the earthquake-induced liquefaction efficiently [33],[34]. The evaluation of liquefaction resistance of soils can be performed using the approaches suggested by [35],[36],[37],[38].

The SCP method is considered since then as a well-established effective liquefaction countermeasure technique in Japan [39],[40]. The competency of the method and the extensive studies performed on the SCP improved grounds as liquefaction countermeasures are presented in Table 2. The table includes selected studies performed in the laboratory and the field, and along with a few case studies [41],[42]. In practice, the inclusion of SCPs in improving the engineering properties of the original sandy grounds is estimated indirectly by performing the SPT and CPT tests, before and after the improvement of the sandy deposits [43]. The field implementation procedure of the SCP method is often carried out by using the following methodology: Recording the initial SPT-N value of the natural ground to be treated, computing liquefaction potential, and implementing the SCP technique by targeting a final SPT-N value by improving the strength properties of the ground such that the liquefaction potential of the deposit can be minimized [44],[45]. These studies either employed the SPT or CPT or dynamic tests as tools to monitor the performance of the improved ground against the liquefaction hazards [46].

| Reference | Description |
|-----------|-------------|
| [42]      | SCP as liquefaction countermeasure as part of Hsin-Ta power plant site, Taiwan |
| [26]      | Liquefaction characteristics of granular soils with fines |
| [1]       | Liquefaction analysis of SCP improved cohesionless ground |
| [43]      | Measures to counter the liquefaction induced settlement |

Table 2: Overview of selected publications on SCP as a liquefaction countermeasure
nutshell would give an overall view of the SCP method when a detailed insight into the technique's behaviour and performance and will highlight the SCP technique's competency and consistency maintained throughout the years. For budding researchers and industry people, this paper in nutshell would give an overall view of the SCP method when implemented in practical applications.

4. Conclusion
The summarization is attempted since the significance of the amalgamation of the past literature available on sand compaction piles related to cohesive soil improvement and liquefaction resistance is identified. The article would provide a detailed insight into the technique's behaviour and performance and will highlight the SCP technique’s competency and consistency maintained throughout the years. For budding researchers and industry people, this paper in nutshell would give an overall view of the SCP method when implemented in practical applications.

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