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# Influence of Eco-Sand Drains on the Performance of Consolidation Characteristics Founded on Soft Clay Deposits

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**Abstract.** Soft clay deposits are highly vulnerable to severe damages due to its low bearing capacity and poor drainage characteristics. Proper ground improvement techniques are mandated to enhance the performance of these problematic soils. In this regard, the paper aims to study the potential of eco-sand drains in enhancing the properties of the soil deposit, in addition it also aims to promote sustainability. The Eco-sand material is sponsored by ACC Cement Plant, Coimbatore, which was found to be a waste material from limestone quarry. Three gang consolidometer was used to conduct the experiments. The eco-sand was used instead of natural river sand in sand drains. The eco-sand drains were used with area replacement ratios from 0 to 10%. The eco-sand drains were installed in the prepared soft clay sample using a specially designed mandrel. From the detailed experimental study, five different consolidation characteristics such as Coefficient of consolidation, Coefficient of compressibility, Coefficient of volume change, Coefficient of vertical consolidation and Permeability are determined for varying area replacement ration and results are compared with the untreated soft clay deposits. The performance of 6% area replacement ratio of eco-sand drains was found optimum in enhancing the consolidation characteristics and improves the load carrying capacity of the soft clay deposits. From the obtained results, it is strongly recommended that, usage of waste materials such as eco-sand will enhance the geotechnical properties of the soft clay deposits and in promoting sustainability.

**Keywords:** Soft clay, Drainage, Consolidation

## 1 Introduction

In the world, major infrastructure development projects get affected due to expansive soils or ultra-soft soil, due to its high compressibility, high moisture content, poor permeability and very low bearing capacity (Kirmani, 2005; Shadab, 2013; Indraratna et al., 2016). There are several ground improvement techniques such as Sand drains, Sand compaction piles (SCP), Sand wick drains and Prefabricated vertical drains are available to remediate the problems associated with the soft clay. Sand drains are one of the traditional ground improvement techniques and have been used extensively to accelerate the consolidation process of soft clay sub soil by preloading. This method

possesses many advantages. Firstly, it accelerates the consolidation process by reducing the drainage path in radial direction and also it reinforces the soft clay layer to provide a better bearing capacity of the overall foundation Atkinson and Eldred (1981); Long (1991); Kirmani (2005).

The consolidation of the soil is the process of expelling some volume of water from the pores between the solid particles. Hence, the rate of consolidation is controlled by the compressibility, permeability and the maximum length of the drainage path. In this study, the effectiveness of Eco – sand drains were evaluated by modeling its behavior in three gang consolidometer apparatus available in SNS Engineering, Coimbatore. Sand drains are constructed by driving down casings or hollow mandrels into the soil. The holes are then filled with sand, only after casings are removed. When a surcharge is applied at ground surface, the pore water pressure in the clay will increase, and there will be drainage in the vertical and horizontal directions. The horizontal drainage is induced by the sand drains. Hence, the process of dissipation of excess pore water pressure created by the loading and hence the settlement is accelerated Naga and Bouazza (2009); Radhakrishnan (2010); Deng et al (2014); Nogami (2015); Bo et al (2017).

The Eco-sand was collected from ACC Cements, Madukkarai Cement Plant, Coimbatore. Eco-sand is a very fine particle, a by–product from cement manufacture which can be used to increase the efficiency of the soil. The generation of Eco-sand is approximately 500 Tons per day and is disposed as a waste. As sustainability in geotechnical engineering field is the need of the hour, by utilizing the eco – sand instead of natural river sand in the construction of sand drains, the sustainability is attained to a greater extent.

## 2 Materials

### 2.1 Soil Sample

Representative soil sample is collected in SNS college of engineering campus. The locations are 11.0178 N and 76.9380 E. The properties of the soft soil are tabulated in the Table 1.

**Table 1.** Properties of soft clay

| S. No. | Properties | | Results |
|---|---|---|---|
| 1. | Initial Moisture Content | | 13.80% |
| 2. | Specific Gravity | | 2.7 |
| 3. | Dry Sieve Analysis | % of Gravel | 2.4% |
| | | % of sand | 25.3% |
| | | % of Silt & Clay | 72.3% |
| 4. | Free Swell Index | | 55% |
| 5. | Liquid Limit ($w_L$) | | 58% |
| 6. | Plastic limit ($w_p$) | | 29% |
| 7. | Shrinkage limit ($w_s$) | | 14% |
| 8. | Flow Index ($I_f$) | | 16.68% |
| 9. | Plasticity Index ($I_p$) | | 29% |
| 10. | Soil Classification | | CH |
| 11. | Optimum Moisture Content | | 21.6% |
| 12. | Maximum Dry Density | | 1.682 g/cc |

## 2.2 Eco-sand

The Eco-sand was collected from ACC Cements, Madukkarai Cement Plant, Coimbatore. The Eco-sand is shown in the figure 1. The properties of the eco-sand are tabulated in the Table 2.

**Fig. 1.** Eco-sand collected from ACC Cements, Coimbatore

**Table 2.** Properties of Eco-sand

| S. No. | Properties | | Results |
|---|---|---|---|
| 1. | Initial Moisture Content | | 4.50 % |
| 2. | Specific Gravity | | 2.66 |
| 3. | Dry Sieve Analysis | % of Gravel | 0 % |
| | | % of sand | 96.3 % |
| | | % of Silt & Clay | 3.7 % |
| 4. | Soil Classification | | SP |
| 5. | Permeability (m/day) | | 0.252 |

# 3 Experimental Works

## 3.1 Experimental setup

The Three gang consolidometer test was conducted as per IS 2720 (Part – 15), 1986, using soil sample of 20mm thickness and 60mm diameter.
The area replacement ratio formula used in the study was discussed below,
Area replacement ratio (%) = Area of the improvement zone / Total area of the specimen
The ratio will vary according to the number of eco-sand drains installed in the test-setup. Higher the number of drains; higher the area replacement ratio.

## 3.2 Installation of drains

The Eco-Sand Drains (ESDs) are installed through the mandrels. Circular mandrels are used for the ESDs. The mandrels are installed with utmost care without disturbing the soils to a greater extent. The mandrels are fabricated according to the various sizes and shapes so as to ease the installation. Experimental procedure

1. For Consolidation testing, it is generally desirable that the applied pressure at any loading stage be double than the preceding stage. The test may therefore be continued using a loading sequence which would successively apply stress of 0.1, 0.2, 0.5, 1.0, 2.0, 4.0, and 8.0 kg/cm2 on the soil specimen.
2. For each loading increment, after application of load, readings of the dial gauge shall be taken using a time sequence such as 0, 0.25, 1, 2.25, 4, 6.25, 9, 16, 25, 36, 49, 64, 81, 100 minutes and 24 hours. These time sequences facilitate plotting of thickness or change of thickness of specimen against the square root of time or against log time.
3. The data concerning dial readings with time for each pressure increment for both loading and unloading stages shall be recorded.
4. The data obtained after specimen assembly concerning the final wet weight of the specimen and the dry weight shall be recorded.

# 4 Results and Discussion

The main aim of the present study is to identify the optimum configuration of the drains. The results were obtained by carrying out the consolidation test in the three gang consolidometer apparatus strictly following the Indian codal provisions. The dimensions of the eco-sand drains used in the experimental study were listed in the table 3.

**Table 3.** Dimensions of Eco-sand drains

| S. No | Replacement ratio | Diameter | Depth |
|---|---|---|---|
| 1. | 4% | 12.5 mm | 18 mm |
| 2. | 6% | 15 mm | 18 mm |
| 3. | 8% | 17.5 mm | 18 mm |
| 4. | 10% | 20 mm | 18 mm |

Three parameters are considered for predicting the optimum dimensions of the vertical drains

- Coefficient of Consolidation ($C_v$)
- Compression Index ($C_c$)
- Time taken for 90% Consolidation

The comparison charts are prepared by plotting the e vs log P curve for virgin soil and for all the configurations and the time taken for 90% consolidation was calculated based upon the square root of time plot method. 1 kg/cm$^2$ pressure condition is considered for plotting the square root of time plot graph.

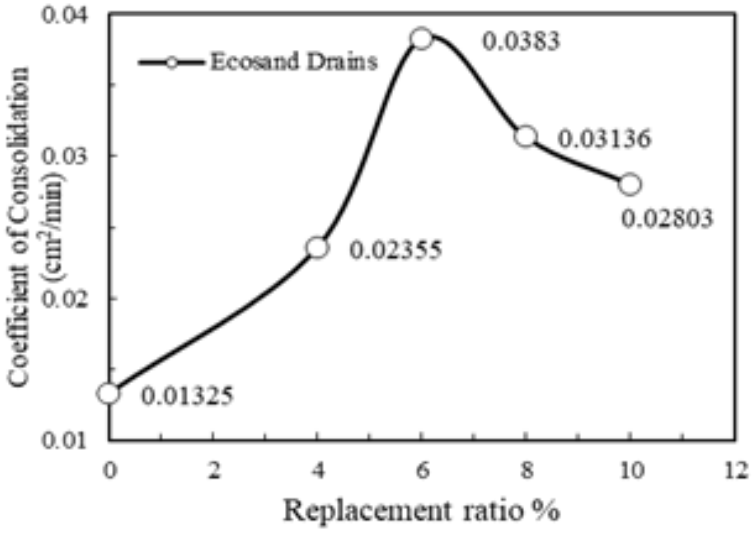


**Fig. 2.** Variation of co-efficient of consolidation with respect to replacement ratio

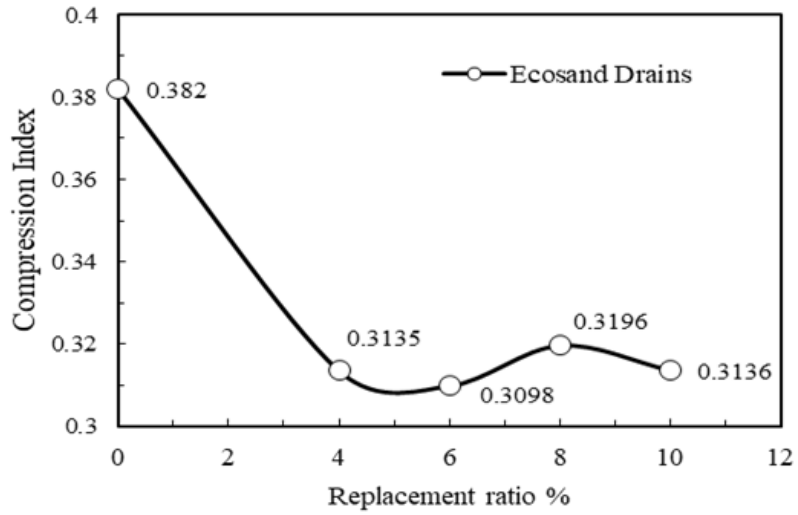


**Fig. 3.** Variation of compression index with respect to replacement ratio

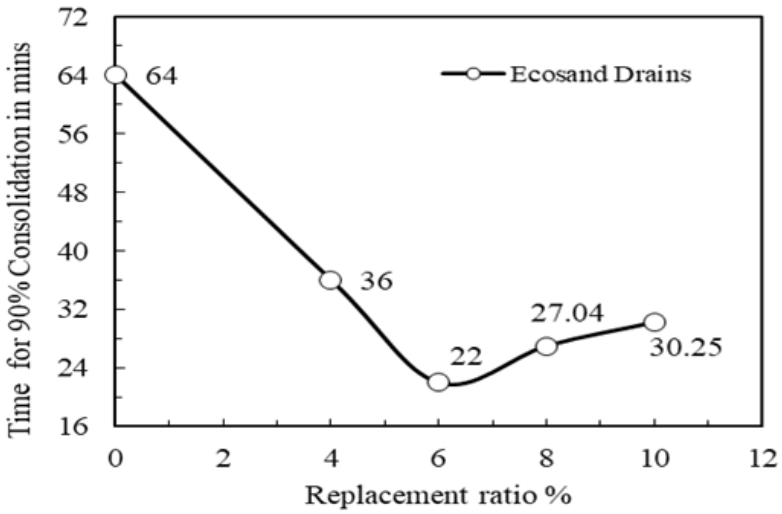


**Fig. 4.** Time taken to attain 90% consolidation with respect to replacement ratio

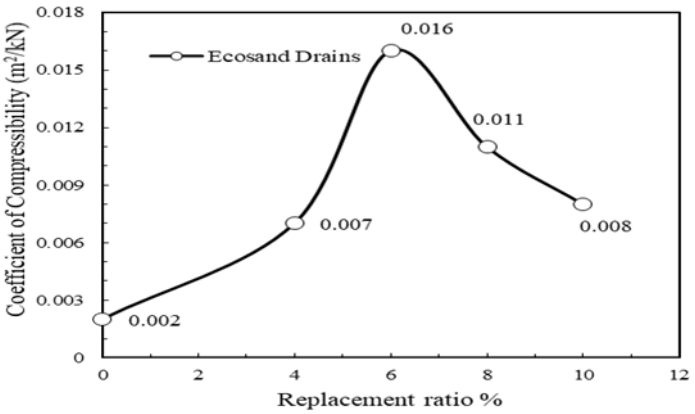


**Fig. 5.** Variation of co-efficient of compressibility with respect to replacement ratio

The consolidation performance Eco-sand drains initially increase with increase in dimensions, once it reaches its optimum configuration, the performance of both the vertical drains starts decreasing with increase in dimensions due to the smear and transition zone effects.

## 5 Conclusions

1. The installation of vertical drains improves the engineering properties and the performance of highly compressible soils to a greater extent, and proves to be a promising ground improvement measure.
2. All the results substantiate that the consolidation characteristics of the highly compressible soils increase to a greater extent due to the installation of vertical drains.
3. The decrease in soil compressibility with a reduction of void ratio has a significant impact on consolidation behaviour.
4. The performance of 6% area replacement ratio of eco-sand drains was found optimum in enhancing the consolidation characteristics and increases the load bearing capacity of the soft clay deposits.
5. The Eco-sand was used instead of natural river sand in Sand Drains in this study, shows potential in improving the performance of high compressible soils under lower cost; and this study provides a solution for the disposal problem of Eco-sand and promotes sustainability.

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