A Study on the Behavior of Recycled Plastic Granular Column Foundation in Soft Soil Under Static and Cyclic Loading

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by

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CHAPTER 7

CONCLUSION AND FUTURE SCOPE

7.1 General

India's unique geological features and the prevalence of soft soils in numerous locations require careful planning and engineering considerations before building embankments over soft soil. The use of granular columns for the reinforcement of soft soils has been done worldwide for several reasons. Granular columns help reduce settlements and increase the stability of highway and railway embankments built over soft soils, enhancing the earthquake resilience of civil infrastructures, short realization time, and significant cost savings over alternative methods. Therefore, using sustainable granular materials instead of conventional aggregates has become imperative, particularly to minimize environmental degradation and tackle problems associated with plastic waste generation.

Granular columns, traditionally composed of stone aggregates, are widely used to enhance the load-bearing capacity of soft soils. However, the depletion of natural aggregates and the environmental challenges posed by plastic waste have led to the exploration of recycled plastic granules as a sustainable alternative.

This study explores the use of recycled plastic granules as an alternative material for aggregates in granular columns. A series of model tests were performed on single granular column stabilized soft clay bed subjected to static and cyclic loading. Furthermore, the performance of an embankment supported by group of end-bearing and floating granular columns (GCs) and plastic granular columns (PGCs) installed in a very soft clay under traffic loading conditions was studied. A detailed description of the methodology, material characterization, scaling and physical modeling details, and model testing process is discussed in Chapter 3. The results tests on model embankment were also validated using finite element analyses with PLAXIS 3D. The major conclusions from all the chapters are listed below.

7.2 Model tests on a single column in static loading conditions

The work presented here describes the performance of GC and PGC-reinforced soft clay beds through the results obtained from experimental and numerical investigations. The following conclusions could be drawn for the various ranges of test conditions mentioned in the manuscript

1. Soft soil modified with granular columns exhibits improved resistance to vertical load-induced settlement. The improvement is primarily influenced by the presence of stiffer granular material in the form of columns within the soil mass.
2. The load-carrying capacity of the granular column improved soil bed increases with the increase in the l/d ratio of the column. However, for a floating column with an l/d ratio of 8, the improvement is significantly closer to that of an end-bearing column. Thus, 8d is reported as the limiting length for the floating column.
3. GC and PGC undergo bulging failure under the action of vertical load. It is evident from the shape of the exhumed granular column after the test and from the numerical modeling results.
4. The use of recycled plastic granules as an aggregate for making the columns has exhibited significant improvement in the load settlement behavior of soft soil. The clay bed having Su of 5 kPa shows 1.83- and 1.9 times improvement in loading capacity for floating and end-bearing PGC, respectively. These results

prove the usefulness of recycled plastic as an alternative and sustainable material for the construction of granular columns.

5. Using geosynthetic encasement improves the effectiveness of GC and PGC in soft soil beds. EGC and EPGC provide further enhancement over the use of GC and PGC in soft soils, but the improvement is drastic for the end-bearing

condition. The use of geosynthetic encasement for an end-bearing column almost doubles the capacity of an encased floating column.

7.3 Model tests on a single column improved soft soil under cyclic loading.

1. The variation of stress concentration for non-encased and encased granular columns was reported in this study. A stepwise decreasing trend of stress concentration was observed for GC and PGC improved soil bed over multistage cyclic loading. A contrasting stepwise increasing trend was reported for EGC and EPGC improved soil bed.
2. Excess pore water pressure variation over multistage cyclic loading has shown a successive increasing trend for granular column-improved soil beds. However, the rate of increment in EPWP is significantly reduced for EGC and EPGC reinforcement combinations.
3. The columns under the loading plate undergo bulging failure for GC and PGC configurations. The columns away from the footing are laterally displaced with no bulging deformation. Encased floating columns undergo punching under the footing with little lateral movement for columns away from the footing. End-bearing columns directly below the footing plate undergo slight buckling.
4. Using geosynthetic encasement with GCs and PGCs significantly reduces EPWP and improves stress concentration on the columns. Embankments

constructed over EGC and EPGC-improved clay beds can better withstand cyclic and static loads.

7.4 Static and cyclic model tests on a supported embankment resting on the soft soil.

1. A model embankment constructed over GC and a PGC-reinforced soft clay bed exhibited significant improvement in settlement response compared to an unreinforced clay bed. The vertical stress under static loading was improved by 71 % and 135 % for floating and end-bearing columns, respectively. Also, the EPWP is reduced by 1.70 times using end-bearing GC.
2. The variation of stress concentration for non-encased and encased granular columns was reported in this study. A stepwise decreasing trend of stress concentration was observed for GC and PGC improved soil bed over multistage cyclic loading. A contrasting stepwise increasing trend was reported for EGC and EPGC improved soil bed.
3. Excess pore water pressure variation over multistage cyclic loading has shown a successive increasing trend for granular column-improved soil beds. However, the rate of increment in EPWP is significantly reduced for EGC and EPGC reinforcement combinations.
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constructed over EGC and EPGC-improved clay beds can better withstand cyclic and static loads.

7.5 Environmental assessment and cost estimation

Past studies have estimated that 50-60% of the plastic waste generated in India is getting recycled. However, 31.5% of the total plastic waste is still mismanaged as litter in the streets, thrown into dumpsites, or burnt openly. The improper disposal of plastic waste, like open burning, emits harmful gases into the environment.

- Plastic waste is usually incinerated for proper disposal instead of open burning to contain air pollution. Studies have been done to estimate the emission during the incineration process of plastic wastes to quantify the environmental impact. Studies have reported that the recycling of plastic waste prevents emissions like 812 kg CO_2 eq/t for Polypropylene (PP) and 144.84 kg CO_2 eq/t for Acrylonitrile Butadiene Styrene (ABS).
- By comparing the cost of recycled plastic granules available in the native market, it was found to cost slightly more ($28–40 per ton) than natural aggregates ($25.5–26 per ton). There might be variation in cost based on the location. However, its use is viable due to their environmental benefits and potential for cost reduction through expanded production and regulatory incentives.
- The outcomes reported in this study shall help in supplementing the available research data needed for promoting the use of recycled plastic granules as an alternative to conventional aggregates. The standardization and quality control in the production process is critical for their wider adoption and assimilation.

7.6 Plaxis 3D validation

- The predictions made by the finite element analyses compare well with the laboratory modeled soft ground improved with groups of end-bearing and floating GCs and PGCs subjected to static loading.
- Both finite element predictions and laboratory model test results show that end-bearing columns give higher failure stress at lower settlement value compared to floating columns.

7.7 Limitations and future scope

The study has the following limitations:

1. The use of recycled plastic granules as an alternative to stone aggregates has been explored in this study, which has not considered the effects of size, shape, and combination of the materials; these could be explored in future research.
2. Field Tests: No field tests were conducted on granular piles with various tire chip-aggregate mix proportions, which could provide insights into compacting challenges and performance comparisons between laboratory and field results.
3. Environmental Considerations: The study did not investigate the potential for leachate formation from using plastic granules, an important environmental concern.
4. Instrumentation: Strain gauges were not used at the interface between the granular pile and surrounding soft soil to measure bulging behavior, which could have provided additional insights.
5. Finite Element Analyses: Drained and undrained 3D finite element analyses under cyclic loading conditions were not explored, leaving room for further investigation.