ABSTRACT

In developing economies like India, there is a significant demand for large-scale infrastructure projects, including high-speed railways, road networks, airport runways, hydraulic structures, ports, oil storage facilities, and industrial complexes. These projects are essential to meet the social and economic aspirations of the population. Several high-impact infrastructure projects like the National High Speed Rail Corridor, Dedicated Freight Corridor, Sagarmala Project, and Expressways are currently being implemented in different parts of India. However, the implementation of these critical projects of national importance faces challenges, particularly the lack of suitable ground conditions, such as soft soils. Soft soils are problematic for construction due to their limited load-bearing capacity and excessive settlement. There is a need to efficiently address problems associated with soft soils.

Ground improvement techniques offer effective solutions to address these issues, with granular columns encased in geosynthetic materials being a widely used method. 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 granular columns (GC) composed of natural aggregates and plastic granular columns (PGC) composed of recycled plastic granules for improving soft soil foundations, particularly in the context of infrastructure development such as embankments for transportation routes and railway systems. The studies also investigate the role of geosynthetic encasement in improving the performance of granular columns under static and cyclic loading conditions.

The research program involved laboratory model tests on soft clay beds reinforced with granular columns. Static and cyclic loading tests were performed on a scaled laboratory 1-g model of a soft clay bed made of kaolin clay reinforced with a single column. The tests performed under static loading conditions evaluated the bearing capacity and deformation behaviors of the reinforced clay bed with respect to the parameters: length-to-diameter ratio of the column, undrained shear strength of the clay bed, column configuration (floating, end-bearing), and use of geosynthetic encasement. The results indicated that granular columns significantly improved the load-bearing capacity of soft soils. Under static loading, vertical load bearing capacity was enhanced by 71–135% for the granular column and 47-93% for the plastic granular column reinforced clay bed, respectively. Geosynthetic encasement further improved performance, doubling the load-bearing capacity in some cases.

Static and cyclic loading tests were also conducted on scaled model embankments supported by a group of granular column improved clay beds. Cyclic loading was applied in single and multi-staged formats to simulate real-world stresses experienced by railway embankments. Stress concentration ratios, excess pore water pressure, and settlement responses were measured using sensors and data acquisition systems.

Cyclic loading tests revealed that granular columns reduced settlement rates compared to unreinforced soil beds. End-bearing columns performed better than floating columns, and geosynthetic encasement further reduced settlement and excess pore water pressure. Stress concentration ratios were higher for end-bearing columns, indicating better load distribution. Excess pore water pressure was significantly reduced in reinforced beds, especially with geosynthetic encasement. Non-encased columns exhibited bulging failure, while encased columns showed reduced lateral deformation and improved resistance to punching and buckling under cyclic loading.

A three-dimensional finite element numerical analysis of the single column and group of columns supporting an embankment was carried out under static loading conditions using Plaxis 3D software. The numerical modeling validated the experimental findings, showing close agreement with observed stress-settlement behavior and deformation patterns. The models simulated the bulging failure of granular columns and the enhanced performance of geosynthetic-encased columns. The results also highlighted the role of geosynthetic encasement in suppressing lateral bulging and improving stress distribution.

The environmental impact assessment and cost estimation of the recycled plastic granules were carried out to ascertain the viability of these materials as a sustainable alternative to conventional aggregates. The environmental assessment highlights that using recycled plastic granules in construction effectively addresses the growing challenge of plastic waste management, reducing greenhouse gas emissions from incineration and minimizing air and marine pollution. For instance, recycling 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). Economically, while recycled plastic granules cost slightly more (\$28–40 per ton) compared to natural aggregates (\$25.5–26 per ton), their use is viable due to their environmental benefits and potential for cost reduction through expanded production and regulatory incentives. Incorporating recycled plastics into granular columns not only promotes sustainability but also offers long-term economic and environmental advantages, making them a promising alternative for construction applications.