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Encased Granular Column as an Advancement over Ordinary Granular Column- A Brief Review

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Abstract. The decreasing availability of stable construction sites has put pressure on geotechnical engineers for improvement of soft soil deposits due to their low bearing capacity and high compressibility. Among various ground improvement techniques available, ordinary granular column is extensively used to improve the engineering properties of soils. Granular column reinforcement techniques possess advantages over other ground improvement techniques especially when there is limited or constrained time for the construction and economically when it is not possible to permit the foundation to undergo natural consolidation process for enhancing its physical and mechanical characteristics. However, the construction of granular columns in soft soils is almost impossible because of the lack of lateral support. Thus the dependability of the granular column on the lateral resistance provided by the surrounding soil can be solved by encasing/encapsulating the column. This advancement was considered as the major milestone in the construction industry. This study is an attempt to get an insight to the columnar technique of ground improvement with major focus on the geosynthetic encased granular columns. Limited practice of this technique is encouraging the geotechnical researchers to carry extensive investigation to understand different aspects related to granular columns under different loading conditions and to highlight various controlling factors affecting the behavior of this technique in soil. Therefore, the aim of this review paper is to discuss the behavior and application of granular column technique, highlight some of the real life field applications of this advanced technique and to compile the latest developments in a single source of information. This study helps in identifying the cases where further research is required.

Keywords: Soft soils; Geosynthetic encasement; Granular column; Ground improvement; Reinforced soil

1 Introduction

1.1 Background

The ground improvement is one of the areas in geotechnical engineering where from last few centuries, many milestones and advancements were seen due to the interesting fact that by this field any proposed structure can be constructed anywhere if proper and efficient technique is implemented. Feeble strength and high compressibility of ground at certain sites becomes the cause and necessitates the use of ground improvement techniques (Mitchell 1985). Deep vibro techniques presents flexible solutions for ground improvement mainly were structures are to be constructed on soil with low bearing capacity. Major challenge among engineers today is the process of ground improvement must be economically sound, eco-friendly, socially credible, sustainable and practically acceptable. Ground improvement techniques implemented by granular column keeping above parameters in mind aids in a stable and permanent solution (Hughes and Withers., 1975; Priebe, 1995; Han and Ye, 2001; Beena, 2010; Castro and Sagaseta, 2011; Debnath and Dey, 2017). The construction simplicity and economical efficiency of this technique makes it an effective ground improvement technique (Black et al., 2006, 2007; Murugesan and Rajagopal, 2010; Yoo, 2010; Fattah, 2011). Granular columns are designed to improve the load bearing capacity of in-situ soils, fills and to reduce differential settlement of non homogeneous and compressible soils. Therefore, allowing the use of shallow foundations and thinner base slabs. Granular column technique can be an economical and sustainable alternative to deep foundation solutions in many site situations. Wide range research is going on this technique since 1980's. This technique is being considered as an effective tool in the construction industry where high settlement can be an issue (Ambily & Gandhi, 2004). Granular columns are formed by inserting a probe into the ground to form the space for incorporation/installation of granular aggregates with high modulus of elasticity than the surrounding soil. As a result the composite ground formed possesses less compressibility and high strength and can absorb more loads. Thus overall the settlement of the soil gets reduced (Kempfert 2003). As of now there has been vast advancement in foregoing deep densification techniques, many of the recent advancements revolves around the mitigation of seismic risks. Considering the granular column technique already posses an upper hand due to this fact that it can act as drains, can be used as landslide control measures and can reduce liquefaction potential. From the past three decades several design approaches regarding the analysis and behaviour of granular columns have been proposed starting with passive pressure approach (Greenwood 1970, Hughes and Withers 1974), general shear failure approach (Madhav and Vitkar 1978), cavity expansion approach, unit cell approach, empirical approach and finite difference approach.

Depending upon the existing condition/stability and ground water level at the proposed site, different methods can be employed for the column construction. The construction of granular columns may be generally carried out by the vibro compaction method, vibro replacement method, vibro displacement method or by cased borehole method. The effectiveness of this technique depends on the lateral restrain or primarily governed by the maximum radial reaction of the surrounding soil (Hughes and Withers, 1974; Ambily and Gandhi 2004). However due to lack of lateral confinement or reaction the application becomes limited, for soft/weak and organic soils this technique is not generally suggested suitable or there is need for some pre treatment before proceeding with this technique (Alexiew et al., 2005,2015; Kempfert, 2003; Kahyaoglu 2017).

1.2 Encased Granular Column as Solution

Granular columns are considered to behave like piles (semi-rigid) considering the bearing capacity, which is contributed to the increased stiffness and also perform the work of vertical drains (Ambily and Gandhi, 2004; Kempfert 2003). However due to inadequate lateral support provided by the surrounding soft/marginal soils to the columns, the construction of the conventional granular columns became difficult and the application of technique become limited, also the soil may flow into the voids of the column which may cause clogging thus leads to a negative impact on the drainage property of column (Hughes and Withers, 1974; Kempfert, 2003; Ambily and Gandhi, 2004; Alexiew et al., 2005; Kahyaoglu, 2017). To withstand the conditions were the soil offers less or minimal lateral support to the granular column technique, some binder can be added to column material to reduce its dependability on the radial reaction of the surrounding soil but the unique properties of column technique to act as vertical drains and to accelerate the consolidation rate will be compromised (Kempfert 2003). Therefore encasing/encapsulating the column becomes an efficient alternative for widening the applications of columnar techniques. Encasing whole or the part of the column with the geosynthetic encasement proves to be the efficient method (Alexiew et al., 2005, 2015; Malarvizhi, 2007; Wu et al., 2014). The application/ advantages of this innovative eco-composite system over the conventional granular column technique are as:

1. The encasement isolates the granular column from the surrounding soil. Thus acts as a filter so the clogging, which possesses negative effect on the permeability of the granular material, is resolved and consolidation accelerates.
2. The technique can be used in the projects where high settlement control is needed which cannot be gained from the ordinary columnar technique.
3. The encased granular columns possess high integrity as the consistent diameter is maintained by the encapsulation which in turn imparts high load carrying capacity to the structure. The differential settlement problem is solved by its proper design. This innovative design solution can be used at the places were layered strata will be present, as the dependibity of the column on the surrounding soil characteristics is bypassed.
4. The shear stress-normal stress analysis of the encased column technique showed the improved behaviour of the composite soil. The encasement not only introduces the pseudo cohesion but also increases the angle of internal friction.
5. The encased granular column possess major economical manifold over the ordinary granular column. The number of the granular columns used for a particular project gets reduced and columns of even smaller diameter can deliver same strength and reduction in settlement.
6. Liquefaction mitigation is one of the major advantages of this technique (Gniel and Bouazza, 2009)
7. The application of the encased columns (GEC) has been used successfully in various engineering practices (Raithel and Kempfert, 2000; Kempfert, 2003; Raithel et al., 2005). Being the recent improvement technique, there is need for the proper understanding of the method and of the principal parameters that can

act as the controlling factors in improving the column behavior and are of supreme importance. The installation process of encased stone column is shown in Fig.1 and Fig. 2.

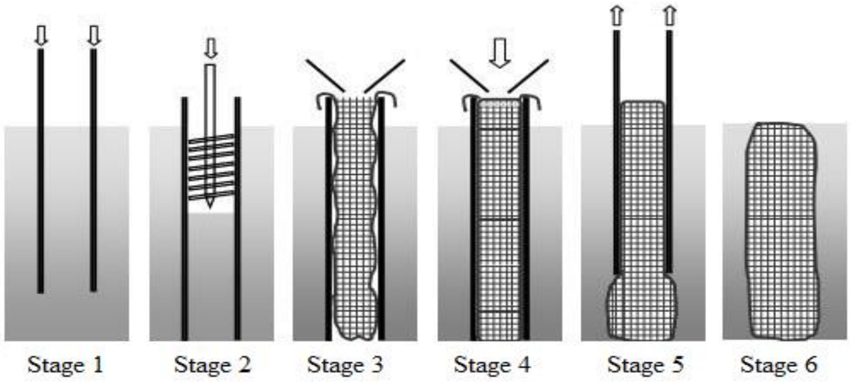


Fig.1. Execution processure of Replacement Method (Gniel and Bouazza, 2010)

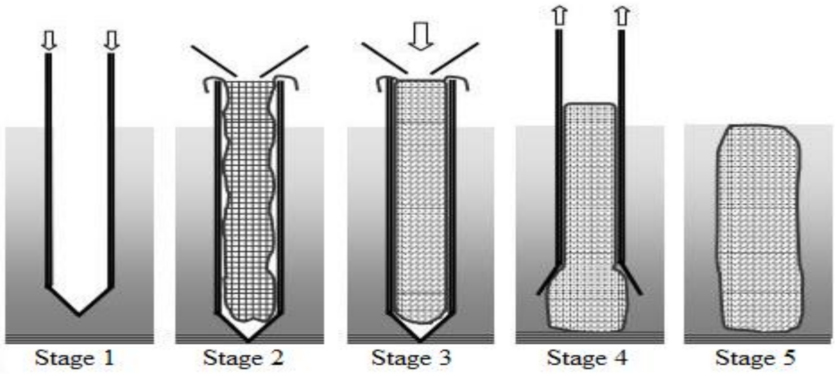


Fig. 2. Execution procedure by Displacement Method

2 Modes of Failure of Granular Column

The possible modes of failure of granular columns under compression loading are: bulging failure, punching failure and general shear failure. Different modes of failure of granular columns under different conditions are shown in Fig. 3. However the bulging type of failure is considered to be the most common type of failure that if goes beyond the permissible limits leads to lateral shear within the column and influences the integrity of the columns and the above super structure. Column bulging is seen maximum close to the top of column due to less overburden pressure. (Arvizhi and Amparuti, 2007; Ambily and Gandhi, 2004; Gniel and Bouazza, 2009; Najjar et al., 2010; Andreou et al., 2008; Gu et al., 2016; Miranda, 2016,2017)

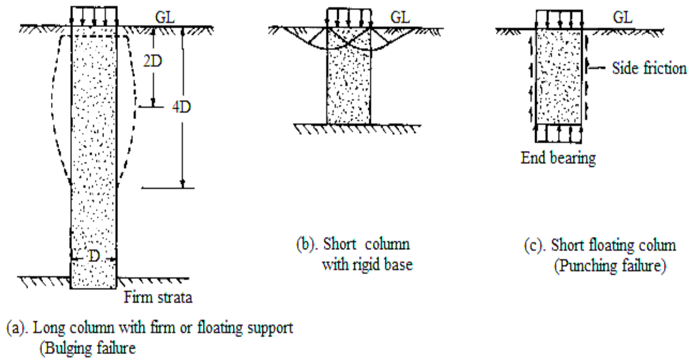


Fig. 3 a. Modes of failure of a single stone column in a homogeneous soil layer (IS 15284 Part 1 2003)

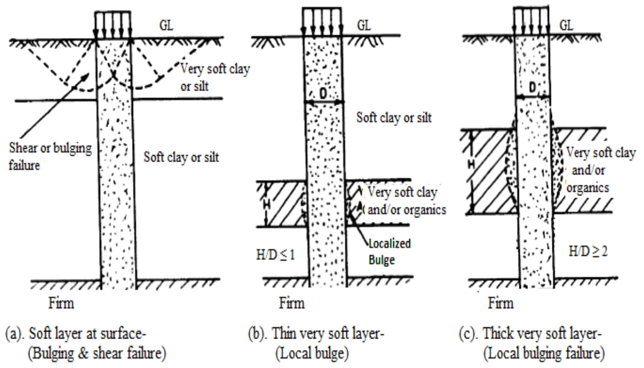


Fig. 3.b. Modes of failure of a single stone column in non-homogenous soil layer (IS 15284 Part 1 2003)

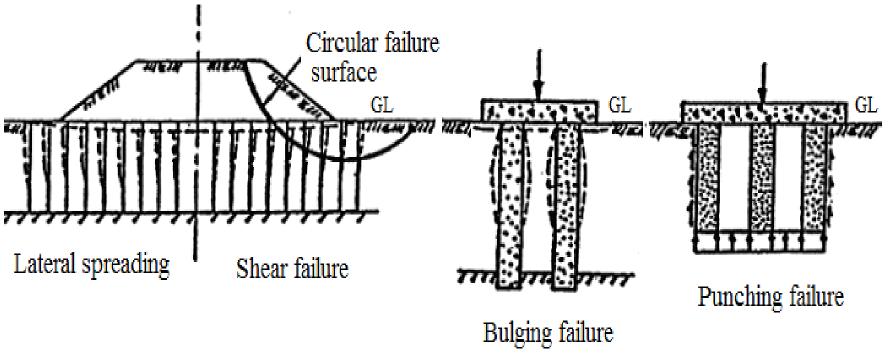
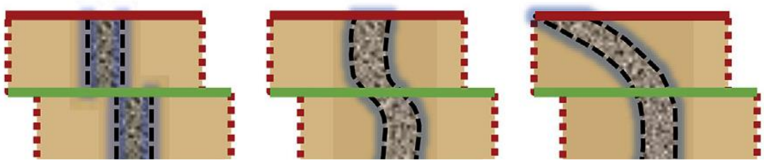


Fig. 3.c. Modes of Failure of stone column group (Barksdale and Bachus, 1983)

General understanding of granular column failure modes rarely extend beyond the failure mechanisms initiated by vertical loads. the research on the behaviour of the ordinary and encased granular columns under vertical loads are being taken from a long period and is somewhat well understood (Hughes et al., 1974; Mitchell and Huber, 1985; Deshpande and Vyas, 1996; Raithel and Kempfert, 2000; Kempfert, 2003; Ambily and Gandhi, 2004; Sivakumar et al., 2004, Alexiew et al., 2005; Murugesan and Rajagopal, 2006,2010; Malarvizhi and Ilamparuthi, 2007; Andreou et al., 2008; Gniel and Bouazza, 2009; Wu et al., 2009; Najjar et al., 2010; Castro et al., 2011,2013; Ghazavi and Afshar, 2013; Schnaid et al., 2014; Frikha et al., 2015; Almeida et al., 2015; Miranda et al., 2016,2017; Debnath and Dey, 2017; Chen et al., 2018; Jayarajan and Rajgopal , 2019; Farah and Nalbantoglu, 2020**).** These studies include analytical, numerical modeling, laboratory investigations and field studies. Research is going on understanding the load deformation by soil arching effect. Rui(2019) studied the development of soil arching by multi trapdoor testing for both conventional as well as reinforced pile supported embankment system. However there are failures that are less recognized which are initiated by the lateral loads and are equally important thus need to be studied, explored and well documented equally. These failure modes are shear failure and bending failure (Mohapatra et al., 2016; Cengiz et al., 2018, 2019).

Mohapatra (2016) attempted to understand the behaviour of granular columns subjected to lateral loads by conducting large scale direct shear model tests. From the test results both quantitative and qualitative improvement in the form of increased angle of internal friction and development of pseudo cohesion was observed by encapsulation of the granular column. The ability of this eco-composite to resist the shear failure of the columns or the whole system thus can also be utilized in case of infrastructure development in seismic regions.

Cengiz (2018) conducted large scale shake table test to understand the behaviour of this technique to seismic excitations. Three different geotextiles were used for encapsulation purpose. Encasement stiffness was seen to play a great role in reducing the magnitude of seismic induced horizontal strains. Stress controlled vertical load test was also conducted to note the post seismic effect on the bearing capacity of the whole system. Cengiz (2019) highlighted three types of problems in granular columns when subjected to lateral loadings shown in Fig. 4.



Shear type Failure **Shear Type Failure** **Bending type Failure**

Fig. 4. Shear failure problems when the column is subjected to horizontal forces (Cengiz and Guler, 2019)

He studied the behaviour of the ordinary and encased granular column under static and cyclic lateral loads. For this study a unit cell shear device was developed having the function of shearing the cylindrical large size soil samples. From the static shear test the shear resistance was seem to be increased by 14% to 90% depending on the encasement stiffness. Similarly a remarkable increase in the shearing resistance was observed during cyclic sinusoidal loading.

3 The Case Studies-Practical Examples

In this section of the paper some of the major projects taken up till know are mentioned. Starting with the Hamburg, Germany (1995), a railroad going to the harbor required widening to meet the increased traffic demand. From the site investigation, soft saturated clay and peat subsoil condition was found. For the construction of the new embankment of 5m height approx. encased column system were employed. This was the first field application of this system. For this project 0.2 to 0.3 area replacement ratio was suggested and used with the column diameter of 1.54m. For the encasement purpose, geosynthetic material with tensile strength of 200KN/m was used.

One of the important projects related to encased granular columns is site of the airplane dockyard (2000) in Hamburg-Finkenwerder on river Elbe (Kempfert, 2003). For the extension, a new dike was constructed over soft soil. The extension of the dockyard shown in Fig. 5 was done by about 140 ha. The boundary embankments of dockyard were supported by 60,000 geosynthetic encased granular column. This is one of the largest field applications of this system till date. The area replacement ratio of 10% and 15% were considered for this project.

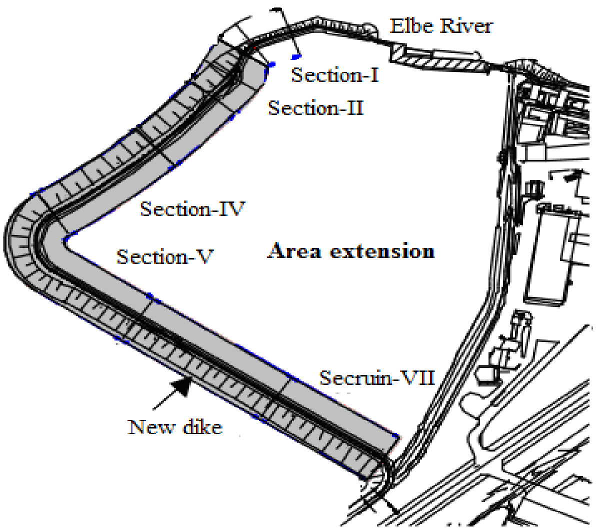


Fig. 5. Layout of the Hamburg dockyard extension (Kempfert, 2003)

The final view of the area is shown in Fig. 6.

Fig. 6. Hamburg air-plane dockyard extension site (Huesker Synthetic GmbH [28])

In Sweden (2001), the Bothnia line (a high-speed railway line) is another field application. The line passes through a valley with soft soil. The embankment of 9 to 10 m height at the bridge number 4 was constructed over encased column system to meet the settlement requirement. For the encapsulation Ringtrac 400 was used. Being the fastest speed track, the proposed system showed the promising results (Alexiew and Raithel, 2015).

Another high speed railroad link ground problem in Netherland was solved by the encased granular column system. The rail line has to pass over a waste disposal landfill with high chemical aggressivity (Nods and Brok 2003, Alexiew and Raithel, 2015). Polyvinyl alcohol was used to form the encasement keeping the chemical activity and high tensile strength of 300kN/m to 400kN/m in mind. This high-speed railroad connects Paris to Amsterdam.

In south part of Houten, Netherland (2005), a landscape embankment was constructed at the end of the housing project for connecting the residential area with the natural landscapes around. These embankments were constructed on the soft soil, with organic clay type soil on Bastion west side and sandy organic clay on Bastion east side. After analyzing the situation and different construction options, encased columnar technique was found to be most suited.780 columns encapsulated with properties shown in Table 1 were used for both sides.

Table 1. Properties of the column system used (Huesker synthetic GmbH [28])

Geometry	S= 2m, D_c= 0.8m	S= 2.3m, D_c= 0.8m
Column Fill	Sand (ϕ= 32.5°)	Sand (ϕ= 32.5°)
Encasement	Ringtrac 3500PM	Ringtrac 2000PM
	Tensile strength= 200kN/m	Tensile strength= 130kN/m

S= Spacing between columns, D_c= Diameter of the column

In Poland, GECs were used in 2010 for the construction of a highway embankment for the A2 motorway. About 3,400 geosynthetic columns of length exceeding 30m were used and were the longest columns to be used till date with allowable post construction settlement ≤10 cm.

Kirsehir Turkey, 2012 – 2014, high traffic embankment (shown in Fig.7) on 14m soft soil in seismic region, requires an underwater foundation for 22 m length. The system comprises of the encased columns with three layers of basal reinforcement. Installation was carried out in water of about 7m depth.

Fig. 7. Location of the embankment (Husker groups [27])

4 Conclusions

The geosynthetic encased granular column system need to be executed worldwide. The only verified codal design procedure EBGEO, 2011 is available. Based on the aforementioned review, the conclusions are as follow:

1. The dependability of the granular column technique on the response of the surrounding soils can be resolved by the encapsulation of the column within a suitable geosynthetic material. For many critical project circumstances with undrained shear strength less than 15kPa, it can prove to be an optimized solution.
2. There is need for full scale systematic field trials of this eco composite to understand the actual working process and to develop better understanding of this system.
3. Comprehensive research pertaining to the understanding of the behaviour of this eco-composite system towards shear loading is needed. This technique need to be designed for both vertical and lateral loading, which will help to enhance the safety and serviceability of the whole geotechnical design.
4. Behaviour of this eco-composite system to cyclic loading (machine load, seismic response, post seismic actions etc) need to be well documented for the wide spread usage of this technique. The ability of the encasement to increase the shear resistance by 14% to 90% can be utilized in case of infrastructure development in seismic regions.

5. The longest geosynthetic encased columns used till date is about 30m with settlement ≤10 cm. These real-life applications of this eco composite system open the doors and prompt the researchers to carry an extensive research in order to widen the application of this technique.

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