Visakhapatnam Chapter

Proceedings of Indian Geotechnical Conference 2020
December 17-19, 2020, Andhra University, Visakhapatnam

Ground Modification Techniques For Deep Soft Soils Sites In Goa Region

Roshani K Majik[1] and Purnanand P Savoikar[2][0000-0001-8660-3045]

[1] Post Graduate Student, Goa Engineering College, Farmagudi – Goa 403401 India
[2] Professor, Goa Engineering College, Farmagudi – Goa 403401 India
psavoikar@gmail.com

Abstract. Soft soils in its natural state are not recommendable for construction purpose as they do not support heavy loads as they have a very low bearing capacity and are susceptible to differential settlement. Soft soils can be improved by adopting various ground modification techniques like deep soil mixing techniques, grouting techniques, using stone columns, incorporating micro piles, dynamic deep compaction, soil stabilization using lime, using prefabricated vertical drains etc. It is necessary to carry out thorough soil investigation before implementing any ground modification technique. Goa lies in the coastal region where the soil is 73% lateritic soil, 10% coastal sandy soils, 12% alluvial and marshy soil and 5% are marine soils. At some of the construction sites in Goa soft marine clay deposits were encountered in the deep soil strata, which contains organic matter and are thus not suitable for construction without improving its properties. This paper discusses the case studies of different sites in Goa where deep soft soils are found. The paper aims at analyzing the soil stratum with the help of bore log data and suggesting suitable methods for ground modification of each site considering low rise and high rise structures to be built on it.

Keywords: Bearing Capacity, Ground Modification, Deep Soft Soils.

1 Introduction

In the recent years, increasing population has lead to rapid urbanization and the demand for construction activities like highways, buildings and other infrastructures has increased. Space constraints and high cost of land for construction purpose has made engineers to utilize the land having weak soils, where the site conditions are not ideal. This is where the geotechnical engineer has to take the charge of improving the soil conditions in order to carry out construction on appropriate stable ground for different civil engineering projects. In the current scenario the role of ground modification techniques has become crucial task for various construction projects. Soils in the coastal belts like marine clay and soft alluvial soils are of weak composition, highly compressible, having very low permeability soft soils generally ranging from silts to clay at various locations and depths. To carry out construction activities in such soils, having low shear strength it is necessary to stabilize the ground before constructing any infrastructure to prevent differential and total settlement and also to prevent liquefaction of the soil.

In the present study, 6 sites were selected in Goa and ground modification schemes haven been designed for each site at Karmali, Margao, Siolim, Merces Vasco, Vaddem Vasco and at Gogol Margao. Geotechnical soil investigations were carried out at these locations in Goa to evaluate the soil strata. Borelog data and soil samples were collected.

2 Literature Survey

The work of installing soil-cement columns besides a metro tunnel station to stabilize the soft soils, deep soil mixing using triple shaft method was proposed by Chen et al.[1]. It was observed that triple shaft caused unacceptable displacement. Thus the field tests were conducted in two phases, Phase I was conducted using single shaft deep soil mixing and in Phase II multiple shaft deep mixing was used to know the factors affecting deep soil mixing process. Finally it was concluded that the installation process could be modified without causing much disturbance by using a higher water/cement ratio at a lower mixing speed.

A detailed study of stone columns, its installation technique, designing of stone columns, equipment requirements and its failure mechanisms was reported by Golakiya and Lad [2]. In this paper, a case study is taken up and the stone columns are designed based on bore log data.

A thorough study on different ground modification techniques, their uses in different type of soils, efficiency of each technique, also how economically feasible they are in the present scenario was reported by Mishra [3].

An overview of the experimental, theoretical and numerical developments of soft ground modification using Prefabricated Vertical Drains (PVDs) along with natural fiber drains combined with surcharge and vacuum preloading was reported where it was found to be efficient and cost effective technique to accelerate consolidation (Indraratna et al. [4]).

Soil modification technique using chemical stabilization is the most successful technique as reported by Nagaraju [5] which presents the potential of geo-polymer technology in soil stabilization that it could be used as an alternative to traditional stabilizers. Geo-polymer stabilization enhances soil properties, has high strength and low cost.

A case study was reported about a case study on ground improvement using stone columns installation followed by testing the integrity of stone columns using plate load test Karthikeyan and Sahu [6]. From the studies it was concluded that, the bearing capacity of the sub soil strata was improved after opting for stone column technique and was found to be efficient and economical.

Design of soft ground improvement using sand compaction pile (SCP) was reported around the abutment of Railway Bridge (Alam et al. [7]). The soil was found to be thick soft clay underlain by medium dense to dense sand layers. In order to control the lateral deformation of abutment, soft clay layer was required to be improved. It was concluded that using very low area replacement ratios (0.06) lateral displacement of abutment can be controlled if SCP is done under and around abutment.

The use of microbial induced carbonate precipitation (MICP) in soft clays was carried out to find out the efficiency of MICP in clay using soft clay specimen samples and mixing it with a solution containing Sporosarcina pasteurii bacteria (solution with different concentrations of nutrient salts) (Xiao et al.[8]). Mixing all these together resulted in formation of calcium carbonate and thus simplifying the soft clays. It was concluded that it is feasible to use microbial induced carbonate precipitation to increase the strength of soft clays.

3 Ground Modification Techniques

Ground modification techniques for shallow weak soils include methods like removal and replacement of weak soil, use of stone columns, dewatering techniques, use of sand compaction piles, sand drains or prefabricated vertical drains, etc. These methods are selected based on types of soils encountered, ground water table position and type of the structure proposed at the site. The new methods like Microbial Induced Carbonate Precipitation (MICP) which has been recently adopted at some sites indicated that certain microorganisms can change the mechanical properties of the soil. This is mainly suitable for sand because sand has a very high permeability and also large grain size. But experiments in clay have shown that it could also be used in clay as a binder. In this method microorganisms are used for increasing the bond between the soil particles which increases the shear strength. This method can only be used for very shallow depths. Bacteria like Micro-aerophilic bacteria, Anaerobic fermenting bacteria, Anaerobic respiring bacteria, etc. are used.

Another latest method of shallow ground improvement is use of colloidal silica. Colloidal silica is used to stabilize the ground to mitigate liquefaction by injecting it into the soil. Colloidal silica is a suspension of silica particles in a liquid phase which are capable of forming hydrogen bonds. Silica particles can be converted to gel by adjusting the pH concentration of the solution. Colloidal silica acts as moisture absorbent when induced into the soil and hence prevents liquefaction of the soil. It can also be used as high temperature binders. It is a very cost efficient technique. Colloidal silica possesses properties like low viscosity and is non-toxic, hence it will not contribute in polluting the ground water resources.

The various ground improvement techniques adopted for deep soft soil sites include methods like vibro compaction, dynamic compaction, blast densification, compaction grouting, jet grouting, permeation grouting, deep soil mixing, ground heating, ground freezing, etc. which are adopted based on type of the soil, ground conditions and type of the structure proposed on the site.

4 Case Studies of Soft Soil Sites in Goa

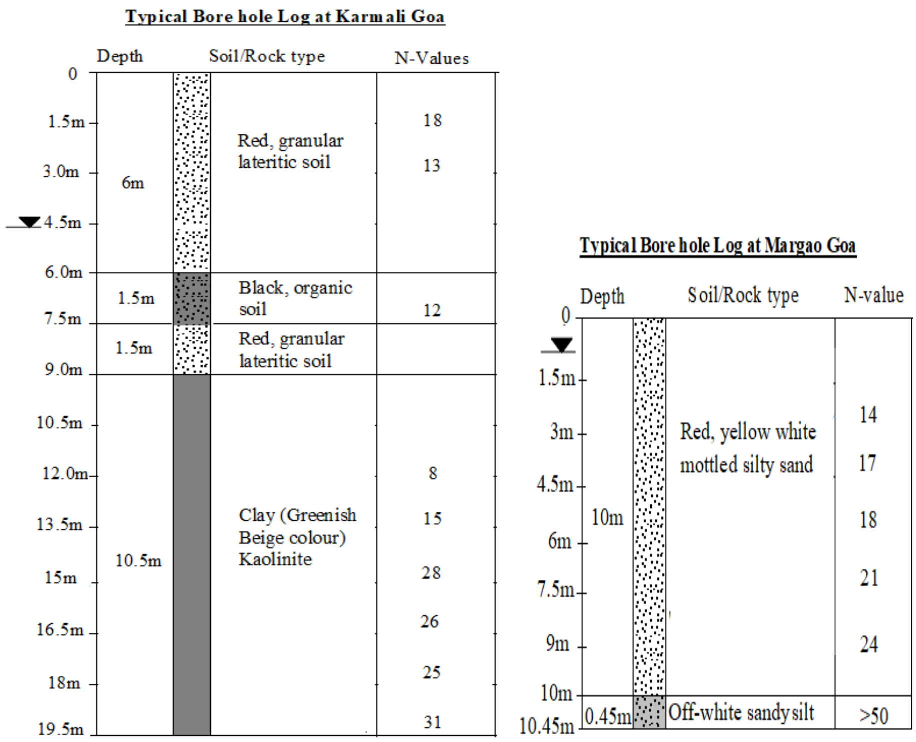
4.1 Introduction

In the present paper, detailed account of ground modification techniques for deep soft soils encountered in Goa is presented. 6 sites were selected in Goa at the following places; at Karmali, Margao, Siolim, Merces Vasco, Vaddem Vasco-da-gama and at Gogol Margao where soft soils were observed.

4.2 Ground modification for soft soil at Karmali (Site – I)

4.2.1 Site conditions

This site is located at Karmali, adjacent to the Carambolim Lake. A G+1 RCC structure is proposed to be built at this site over an existing platform which was built previously. The borehole was drilled up to a depth of 19.5m from the ground level. Borehole log is shown in Fig. 1(a).



(a) **(b)**

Fig. 1. Typical bore logs at (a) Karmali Goa and (b) near KRCL Margao Goa site

4.2.2 Ground modification recommended

As per the site information obtained from the borelogs and laboratory testing, saturated marine clay is encountered at deep depths. The structure to be built is a low rise building hence the soil does not have to carry heavy loads. Hence shallow ground modification is recommended. To stabilize the soil beneath the footings of the G+1 RCC structure, excavation work using an excavator is to be carried out and the soil should be excavated up to a depth of 3.5m. A layer of hard lateritic soil of 60cm should be placed and well compacted below each footing. A plain cement concrete layer of 20cm thick of grade 1:3:6 is recommended. All the columns should be connected to the plinth beams once the footings are complete. Taking into consideration the fact that the second row of columns is close to the bank of the lake and that very soft clay layer exits below, also that the water in the Lake rises during the monsoons it is recommended to provide a cutoff wall near second row of the columns on sloping pitched portion. This cut-off wall can be constructed by extending the plinth beams connecting the column by about 0.8m and providing a vertical small RCC wall which goes into the soil existing in the sloping portion by a meter. This will provide stability to the column near the bank and will prevent the movement of soil from sloping portion into the lake. This would be the most economical ground strengthening technique which could be used to increase the bearing capacity of that area for low rise buildings.

4.3 Ground modification for soft soil at Margao (Site – II)

4.3.1 Site conditions

This site is located at Margao, near to the Railway Station. A mid rise building is proposed to be built at this site. The soil encountered here is soft silty sand. The borehole was terminated at the depth 10.45m. Hard rock stratum was not encountered beneath. The investigation consisted of one test borehole which was drilled up to 10.45m depth. The location of bore hole was selected in consultation with the client. Standard penetration tests were performed in the borings in conjunction with samples. The top layer encountered is red, yellow white mottled silty sand up to a depth of 10m from the existing ground level. SPT values for the same varied from 14 to 24. This layer was followed by off-white sandy silt up to a depth of 10.45m. SPT potential of this layer was more than 50. The water table was found at a depth of 1.0m. Typical bore hole log is shown in Fig.1(b).

4.3.2 Ground modification recommended

As per the geotechnical soil data obtained from the bore logs and laboratory testing silty sand was found at this site up to a depth of 10.0m from the existing ground level. No hard rock or very hard strata was available. Shallow ground modification is recommended to be implemented in order to enhance the soil properties. Since the soil found here is sandy in nature ground modification using Sand compaction piles (SCP's) is the best suited method to be used. Since the water table was found at a depth of 1.0m it is recommended to carry out dewatering using a dewatering pumping system. It was recommended to use a non-vibratory sand compaction piles as the vibratory equipment causes vibrations and noise pollution which disturbs the surrounding environment.

Similar studies were carried out by Bicalho et al. [9] which were based on two case histories densification of loose sands using sand compaction piles. Two cases involving construction of a 10 storey building and a 6 storey apartment building. The results showed the feasibility of installing sand compaction piles for densifying loose soils. The successful installation of piles also resulted in increasing the penetration resistance of cohesion-less soils. It was concluded that these piles produce a more homogeneous density, reducing future differential settlement. Harada et al. [10] reported various case studies which were taken up to evaluate the effectiveness of the soil performance by installation of sand compaction piles and also discussed about the recent developments made in installing SCP's. The studies carried out also focused on the development of the non – vibratory sand compaction pile method over the vibratory method. It was concluded that effectiveness of sand compaction piles was verified and proved through the cases taken up for evaluation.

4.4 Ground modification for soft soil at Dando Siolim (Site-III)

4.4.1 Site conditions

This site is located at Dando Siolim - Goa. A low rise building is proposed to be built at this site. Completely weathered rock was seen till the drilled depth of 9.60 m – 10.12 m. The caculated safe bearing capacity is found to be 15 t/m^2 at a depth of 2.0m where the footing is proposed to be built.

4.4.2 Ground modification recommended

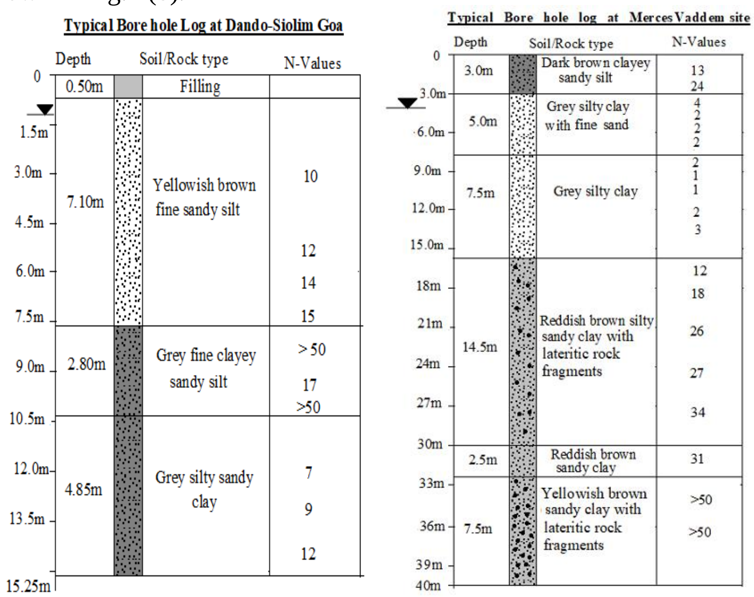
As the structure to be built is a low rise building, no heavy loads are to be taken up by the soil. The ground modification should be done for a depth of not more than 3m. Isolated footings are proposed to be designed for the structure at 2.0m depth. To strengthen the soil beneath, it is recommended to improve the soil by removing the soft layers of the soil for a depth of about 3.5m and replacing it with well compacted and well graded soil. As the water table was found at a depth of 1.10m extensive dewatering should be carried out before implementing the ground modification technique. It is recommended to do ground improvement by removing the top 3.2m soil which is clayey sandy silt from the existing ground level for the entire foundation area (building plan + 2m all around) and laying a layer soil which has requisite properties like lateritic soil for a depth of 50cm and ramming it properly. A layer of rubble soling 20cm thick should be laid over this layer and should be well compacted. On top of rubble soling 30cm of lateritic soil should be laid and rammed. Over this rubble soiling of 20cm should be laid and well compacted. The footings should be constructed over this. This incremental replacement of the layers will definitely result in improving the bearing capacity of soil. To check whether the bearing capacity of the soil has increased it is suggested to conduct a plate load test over the improved soil to ascertain the improved SBC.

Gabr [11] reported that using replacement method instead of deep ground modification methods for light weight buildings over layers of soft soils is an economical solution. In the studies carried out the soft soil replaced with sand and gravel to support light weight building on shallow foundation is examined by using centrifuge test and numerical modeling. From the studies conducted it was concluded that removal of unsuitable soil and replacing it with well compacted soil can reduce the cost and settlement considerably.

4.5 Ground modification for deep soft soil at Merces Vasco (Site – IV)

4.5.1 Site conditions

This site is located at Merces, Vaddem Vasco. A high rise residential building is proposed to be built at this site. From the typical borehole log of 40m, the top layer of the soil observed in the boreholes is dark brown clayey sandy silt of about 3.0m thick. This layer was followed by a layer of greyish silty clay mixed with fine sand from a depth of 3m to 8m. SPT potential varied from 2 to 7 putting it in the soft to medium stiff category. The next layer found was greyish silty clay and the thickness of this layer was found to be 7.50m. The SPT potential of the same varied from 1 to 3 putting it from very soft to soft category. This layer was followed by reddish brown lateritic soil which consisted of completely weathered lateritic rock fragments up to a depth of 40m. Ground water was encountered at a depth of 2.50m to 3.45m below existing ground level. It was proposed to build a raft foundation for the structure at a depth of 1.5m. The safe bearing capacity at site was found to be 150kN/m^2. Typical bore hole log is shown in Fig. 2(b).



(a) **(b)**

Fig. 2. Typical bore logs at (a) Dando-Siolim and (b) Merces Vaddem-Vasco site

4.5.2 Ground Modification Recommended

As per the soil investigation data obtained from the bore logs and clayey sandy silt was found at this site. No hard rock or very hard strata was available even at the depths of 40m. As soil being very soft, the susceptibility to undergo settlement under heavy loads is very high which might result in failure of the structure. In order to create a firm base for the structure to rest on the soil it is necessary to opt for ground modification techniques. As the structure is a high rise residential building it is necessary to carry out ground improvement for a depth of about minimum 15m which will incorporate the area of the pressure bulb of the raft foundation making the soil stable to take up heavy loads. A combination of ground improvement technique of deep soil mixing supplementing vibro stone columns could be an effective solution for improving the ground conditions. By evaluating the sub surface stratum it is suggested to opt for deep soil mixing for a length of 8m to 15m of the bore log. Over this the vibro stone columns should be placed from a depth of about 1.5m to 8m from the existing ground level. The designed raft foundation should be placed over this layer of stone columns at 1.5m depth. Hence, the ground improvement is achieved. After completing ground improvement as above, plate load test can be done to ensure the effectiveness of ground improvement.

Similar method was studied, designed and executed by Shao and Kinley [12] where ground improvement technique for a building resting on alluvial deposits in San Diego, California, USA. The soil strata consisted of alluvial deposits. There were layers of saturated sand present in the soil stratum which were liquefiable. Hence, a combined method of deep soil mixing and stone columns was proposed and implemented which would also control settlement and reduce the risk of liquefaction.

4.6 Ground modification for deep soft soil at Vaddem Vasco (Site – V)

4.6.1 Site conditions

This site is located Vaddem Vasco-da-gama, Vasco. A high rise commercial building is proposed to be built at this site. The soil encountered at this site at shallow depths is very soft marine clay upto 14.0m and hard rock is encountered at a depth of 25m. Very hard amphibolites rock with inclined joints, was encountered at a depth of 23.5m from the existing ground level. Ground water was encountered at a depth of 0.6m below ground level which may vary with seasons. Bore hole log at this site is shown in Fig. 3.

4.6.2 Ground modification recommended

Geotechnical observations show that very soft marine clayey silt is encountered at this particular site approximately at a depth of about 14m and very hard amphibolite rock at 23.5m. Since rock was found at considerable depth thus, it is proposed to build a bored cast in-situ pile foundation to take up the heavy loads and also to control differential settlement. Before commencing the ground improvement work the extensive dewatering should be carried out water table was found at a depth of 1.10m.

Bored cast in situ piles are used at similar sites for improving the ground conditions to take up heavy loads. Anirudhan [13] reported that there have been some defects observed in the bored cast in situ piles which were constructed using rotary drilling rig in South Chennai. It was reported that after the concreting was completed and the temporary casing was withdrawn it was noticed that there is an issue of sinking of concrete by 2.0m in 30 to 40 minutes after concreting. High strain dynamic tests were conducted on the piles were concreting defects were observed, it was reported that pile capacities were decreased from designed 285 tons to 100 tons. From the thorough study of the case it was concluded that the defects occurred due to the inappropriate construction practices and also due to improper identification of the soil stratum. The defect was rectified by installing more number of piles in that area.

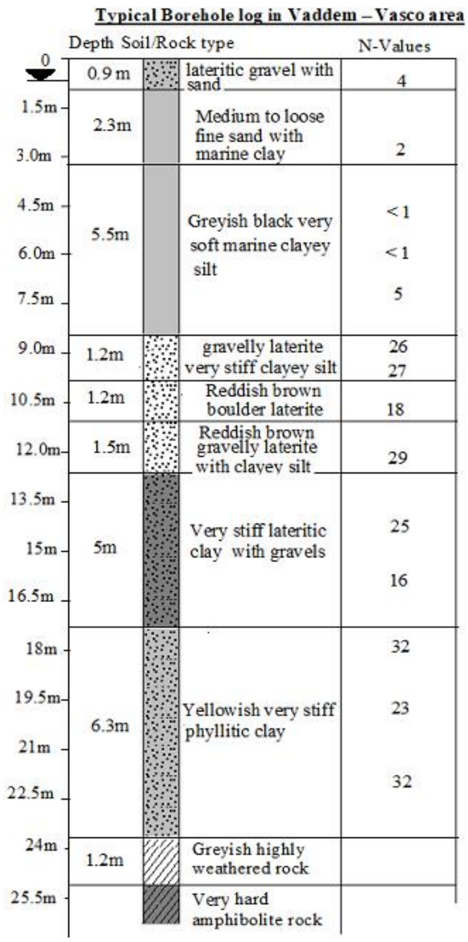


Fig.3. Typical Borelogs at Vaddem Vasco Area

4.7 Ground Modification for Deep Soft Soil at Gogol Margao (Site – VI)

4.7.1 Site conditions

This site is located at Gogol, Margao - Goa. A mid-rise building is proposed to be built at this site. Completely weathered rock was seen till the drilled depth of 9.60 m – 10.12 m. From the typical borehole log of 10.12m shown in Fig. 4, the first layer of the soil observed in the borehole is brownish red clayey silty sand up to a depth of 3.8m approximately. The SPT potential of the same varied from 5 to 10. The next layer observed was brownish yellowish silty sandy clay with some gravels from a depth of 3.8m to 9.8m. This layer was followed by highly weathered rock from a depth of 9.6m to 10.12m.

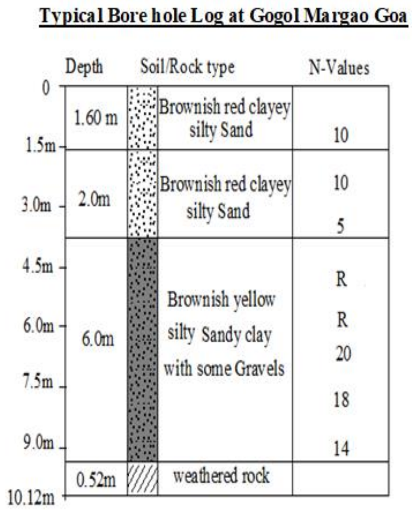


Fig. 4. Typical bore logs at (a) Vaddem – Vasco and (b) Gogol Margao site

4.7.2 Ground modification recommended

The footing is proposed to be built at a depth of 2.00m from the existing ground level. The existing site has very low bearing capacity and very high settlement characteristics hence it is recommended to carry out ground improvement. Since rock was found at considerable depth thus, to control differential settlement and also to increase the bearing capacity of the soil a hybrid composite ground modification method was proposed to be executed at this site which was a combination of vibro stone columns and dynamic consolidation. Providing stone columns in the entire area at the site could be an uneconomical solution thus, it was proposed to concentrate the stone columns only under the footings to control differential settlement at a depth up to which hard stratum was encountered. The stone columns were supplemented with dynamic consolidation to densify the remaining area surrounding the site. After the completion of ground improvement as above, plate load test can be done to ensure the effectiveness of ground improvement. Alternatively, stone column capacity testing can be done.

These ground improvement techniques reduce the excessive settlements by densification.

Similar method was studied, designed and executed by Lopez et al. [14] a composite ground improvement program consisting of vibro replacement columns and dynamic compaction. Three concerns were identified at this site, which were liquefaction susceptibility, low bearing capacity and differential settlement. It was proposed to install the stone columns concentrated under the footing to tackle the differential settlement of the building. Dynamic compaction was proposed to be performed over the entire area even including the area where stone columns were installed. From the study conducted it was concluded that the combination of methods resulted in 40% cost reduction also the silts and clays experienced a surprisingly high level of improvement.

5 Conclusions

Ground modification techniques recommended for different sites depend upon the type of the soil encountered like silt, clay, sand etc., position of ground water table and depth of the soft soil layers. In addition to standard methods like vibro compaction, dynamic compaction, deep soil mixing, stone columns, sand drains etc. the newer techniques like microbial induced carbonate precipitation (MICP) and Colloidal silica are the latest emerging methods being studied. In the present study, shallow ground modification schemes are designed for soft soils encountered at Karmali, Margao and Siolim as low rise and mid rise buildings are proposed to be built which do not have to carry significantly very heavy loads. In the present study deep ground modification schemes are designed for deep soft soils at Merces Vasco, Vaddem Vasco and Gogol Margao as high rise buildings are proposed to be constructed and these soils have to carry very heavy column loads.

References

1. Chen, J., Zhang, L., Zhang, J., Zhu, Y. and Wang, J.:Field Tests, Modification, And Application Of Deep Soil Mixing Method In Soft Clay, Journal of Geotechnical and Geoenvironmental Engineering, ASCE, (2013).
2. Golakiya, H. D. and Lad, M. D.: Ground Improvement by Using Stone Columns, Journal of Emerging Technologies and Innovative Research, 2(11), (2015).
3. Mishra, B. A.: Study on Ground Improvement Techniques and Its Applications, International Journal of Innovative Research in Science, Engineering and Technology, 5(1), (2016).
4. Indraratna, B., Baral, P., Rujikiatkamjorn, C., Nguyen, T. T.: Soft Ground Improvement – Theoretical, Experimental, Numerical and Field Studies, Indian Geotechnical Conference 2018, Indian Institute of Science Bengaluru – Karnataka (2018).
5. Nagaraju, V. T.: Potential of Geopolymer Technology Towards Ground Improvement, ACSGE Proceedings, BITS Pilani (2018).

6. Karthikeyan, A., Sahu, S. K. A Case Study on Ground Improvement Technique Using Stone Column for Secondary Clarifier Resting on Loose Sand, ISSMGE, Symposium on Laterites and Lateritic Soils, Goa (2019).
7. Alam, M. J., Islam, M., Islam, M. S.: Development of Soft Soil Improvement Scheme for Lateral Stability of Railway Bridge Abutment, Proceedings of 9th IACMAG Symposium , Gandhinagar (2019).
8. Xiao,J. Z., Wei, Y. Q.,Cai, H., Wang, Z. W., Yang, T., Wang, Q. H., Wu,S. F.: Microbial-Induced Carbonate Precipitation for Strengthening Soft Clay, Advances in Materials Science and Engineering, 2020, Article ID 8140724 (2020).
9. Bicalho, K. V., Castello, R. R., d'Andréa, R. :The Densification Of Loose Sand Using Compaction Piles, 5th International Conference on Case Histories in Geotechnical Engineering, New York, (2004).
10. Harada, K., Tsuboi, H., Tanaka, Y., Takehara, Y. and Fukada, H.:Cases Histories and Recent Development of the Sand Compaction Pile Method as a Countermeasure against Liquefaction, Proceedings of the 5th International Conference on Case Histories in Geotechnical Engineering, New York (2004).
11. Gabr, A. K. :The Uncertainties of Using Replacement Soil in Controlling Settlement", Journal of American Science, 8(12), (2012).
12. Shao, L., and Kinley, J, :Vibro Replacement and Soil Mixing Ground Improvements at a Shopping Mall Site in San Diego, California, USA, Proceedings of the 5th International Conferences on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics and Symposium in Honour of Professor I. M. Idriss, (2010).
13. Anirudhan, I. V.: Construction of bored cast-in-situ piles using rotary drilling procedure – A case study, Proceedings of Indian Geotechnical Cinference, IGC2009, Guntur, India (2009).
14. López, R. A., Mathew, J. F., Rollins, K., Davis, S. W. and Batchko, Z.: Composite Ground Modification System: Vibro-replacement and Dynamic Compaction, Salt Lake County Detention Center, Utah. Fourth International Conference on Case Histories in Geotechnical Engineering, St. Louis, Missouri (1998).