Geotechnical and Geophysical Site Characterisation 5 – Lehane, Acosta-Martínez & Kelly (Eds)

Influence of periodic hydrocarbon contaminated bentonite on strength and settlement characteristics of stone column

M.V. Shah & H.C. Chokhawala
Applied Mechanics, L.D. College of Engineering, Ahmedabad-380015, India

ABSTRACT: Many coastal areas (marine soils) is largely facing oil/gas spillage which leads to hydrocarbon contamination of this soils. With period of time this hydrocarbon creates major changes in soil engineering properties. Present research is attempt to study the geotechnical properties of hydrocarbon contaminated bentonite (Less expansive) using singular and group of stone columns. Experimental work is contingent on IS 15284 (part-1) to evaluate the settlement response of stone column in 3% and 6% artificially hydrocarbon contaminated calcium bentonite clay as single (Unit cell) and in a group of column (triangular pattern). Compressibility characteristics of stone column and improved shear strength of soil mass is major concern of this research work. Overall results depicted that there is major influence of periodic hydrocarbon contamination on compressibility characteristics of soft clays and can be sufficiently reduced by infusing stone column.

1 INTRODUCTION

Hydrocarbon soil contamination is very common in marine clays. Petrochemicals, hydrocarbons (oil spills), are extensively liberated onto the surrounding soil and get penetrated into the deep ground soil further affecting its physico-chemical properties. This necessitated the use of land, which has weak strata, wherein the geotechnical engineers are challenged by presence of different problematic soils with varied engineering characteristics. Many of these areas are covered with thick soft marine clay deposit, with very low shear strength and high compressibility.

Several researchers have worked on stone column by varying the spacing between column, length of column, diameter of column, different materials of column and also varying of surrounding soils condition like soft soil to fine sand and layered soils. Some has also reinforced stone column by different geosynthetic materials. Very few work has been done to improve hydrocarbon contaminated soft clays by stone column.

In experimental approach, Hughes and Withers (1974) carried out series of model tests in normally consolidated clay. The test results indicated that ultimate capacity of stone column was governed primarily by the maximum radial reaction of the soil against the bulging and the extend of vertical movement in the stone column was limited to about 4 times the diameter. Shankar and Shroff (1997) conducted experimental studies to study the effect of pattern of installation of stone columns and showed that triangular pattern seems to be optimum and rational. Madhav (2000) presented an overview of recent contributions for the analysis and design of stone columns. Different equations available in the literature for finding bearing capacity and settlement of stone column improved ground have also being given. Aimbly & Gandhi (2007) carried out several test by varying spacing between column, shear strength of soft clay and loading pattern. Result observed that by increasing spacing and decreasing shear strength of column axial load carrying capacity is decreasing. Tandel & Solanki (2012) tested performance of stone column with and without geosynthetics and result showed that with reinforcement stone column axial load carrying capacity is increased by two folds and in that role of different geosynthetic had also played a vital role in the performance of stone column.

2 EXPERIMENTAL INVESTIGATIONS

Following objectives are conducted in present work.

1.) To evaluate Index and Engineering properties of non-contaminated and periodic hydrocarbon contaminated calcium bentonite clay.

2.) To evaluate the axial load carrying capacity of stone column in Non-contaminated clay, 3% and 6% hydrocarbon contaminated clay.

3.) To evaluate the improved shear strength of ground after infusion of stone column by means of van shear test.

Accordingly two type of test were carried out in the large size oedometer of different size (d=250mm & d=600mm). For single column and group of three column in triangular pattern.

2.1 Experimental set-up

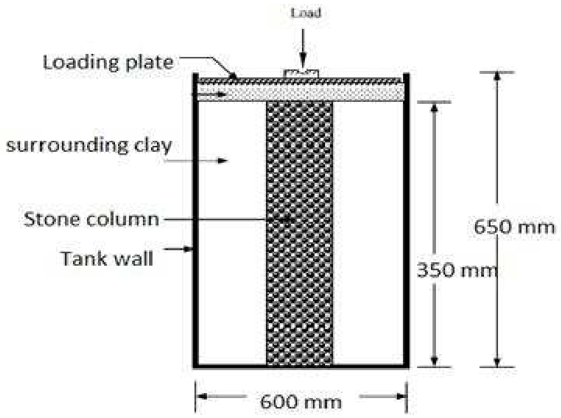


Figure 1 Schematic diagram of stone column arrangement

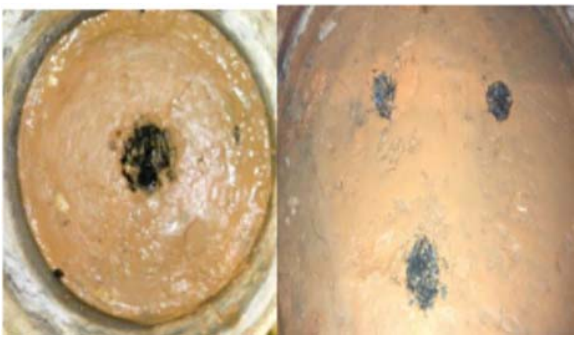


Figure 2 Installation pattern of stone column

All experiments were carried out on a 50 mm diameter stone column surrounded by soft clay in cylindrical tanks of 650 mm high and a diameter varying from 250 to 600 mm to represent the required unit cell area of soft clay around each column assuming triangular pattern of installation of columns. For single column tests the diameter of the tank was taken 250 mm and for group tests on 3 columns, 600 mm diameter was used. Tests with entire area loaded were used to study the stiffness of improved ground.

2.2 Test set-up

The stone column was extended to the full depth of the clay placed in the tank for a height of 350 mm so that *l* /*d* ratio (length of the column/diameter of the column) is a minimum of7, which is required to develop the full limiting axial stress onthe column (Mitra and Chattopadhyay 1999). Vertical stress wasapplied either over the entire tank area. The loading pattern and displacement observation pattern was thoroughly follow IS: 15284 Part-1 (2003).

Tests were also carried out on a group of three columns arranged in a triangular pattern where the clay area corresponding to an equivalent area of three unit cells is represented by the tank area as shown in Fig. 2 to compare the behaviour with a single column and to check the stress distribution between stone column and clay. The load was applied through a 16 mm thick wooden plate to ensure negligible structural deformation.

2.3 Properties of material

Three basic materials are used in the testing program. Non-contaminated calcium bentonite, Hydrocarbon contaminated (3%, 6%) calcium bentonite clay, Hydrocarbon sample and stone aggregates.

2.3.1 Properties of clay

Table 1 Properties of NC clay and 3%, 6% C clay

Properties	NC	3%C	6%C
Specific gravity	2.1	2.18	2.25
Liquid Limit (%)	249	205	186
Plastic limit (%)	57	85	110
Plasticity index (%)	192	95	76
Maximum dry density (kN/m ^{3})	18.36	18.69	19.1
Optimum water content (%)	20	18	16.5

Table 2 periodic contamination effect on Liquid Limit, plastic limit & shrinkage limit

Properties	Period in days			
	0	15	30	45
LL_3%	242	239	205	197
LL_6%	235	170	186	150
PL_3%	118	115	85	102
PL_6%	125	122	110	114
SL_3%	45	38	22	21.5
SL_6%	43	29	23	27

2.3.2 Properties of stones

Crushed stones (aggregates) of size below 8mm have been used to form stone column. The finer fraction passing through 2mm was removed by wet sieving and used after drying. Typical properties of aggregate for stone column are:

Table 3 Properties of stone aggregates

Internal friction angle	35^0
Particle Size	2mm-8mm
Coefficient of curvature	1.125
Uniformity coefficient	2

2.3.3 Preparation of clay bed

Initially clay was mixed with water equal to 2 times the liquid limit of the soil by kneading in a large tank to form a slurry that was free from lumps and remove past stress if any. This pressure is allow to consolidate under its own weight for 1 day and then after consolidate under 20 kPa to make a clay bed. Drainage is permitted at the top and the bottom layer by placing porous plates. This process continued for 8-10 days until the required clay bed shear strength is been achieved. This procedure yielded clay beds of uniform moisture content and consistency.

2.3.4 Construction of Stone Column

All stone columns were constructed by a replacement method. A thin open-ended seamless PVC pipe of 50 mm outer diameter and wall thickness 2 mm was pushed into the clay at the centre of the tank up to the bottom. Stones were charged into the hole in layers with a measured quantity of 0.65 kg to achieve a compacted height of 50 mm. The pipe was then raised in stages ensuring a minimum of 5 mm penetration below the top level of the placed gravel. To achieve a uniform density, compaction was given with a 2.5 kg circular steel tamper with 10 blows of 100 mm drop to each layer. The corresponding density was found to be 16.62 kN/m^3. The procedure was repeated until the column is completed to the full height

3 RESULT AND DISCUSSION

Following are the results and discussion on settlement characteristics of stone column in hydrocarbon contaminated clays.

1. Axial load carrying capacity of stone column
2. The load resistance offered by stone column is computed at different settlement interval in N/mm.

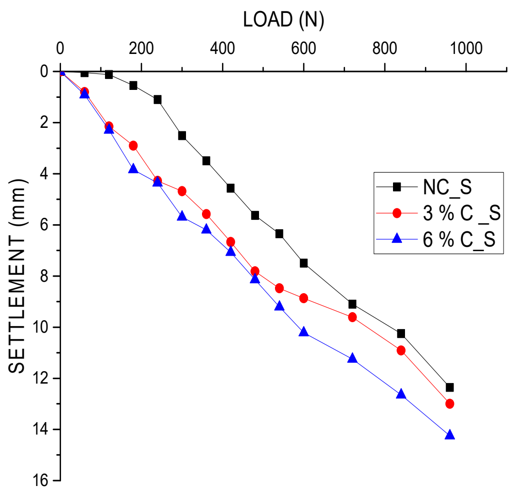
Load resistance = *change in load/change in settlement*

3. Improved shear strength of soil mass
4. Moisture content profile
5. Bentonite-hydrocarbon interaction, Bentonite-hydrocarbon-Stone column interaction

3.1 Axial capacity of stone column and load resistance

This analysis aims at evaluating the improvement of the stiffness of the treated ground. The loading of both the stone column and the surrounding equivalent area with confinement of the tank wall represents an actual field condition for the interior columns of a large group of stone columns. Fig. 3 & 4 shows typical axial stress versus settlement behaviour for non-contaminated as well as 3%, 6% contaminated clay.

1. The ultimate load obtain from the graph for NC clay is 1080, 3%C clay it is 1020N and 6%C clay it is 960N for single column.
2. The ultimate load obtain from the graph for NC clay is7200N, for 3%C clay it is 6840N, and 6%C clay it is 6660N.
3. It is observed that load carrying capacity of stone column is decreasing 12.5% in 3% hydrocarbon contaminated clay and 20% in 6% hydrocarbon contaminated clay with compare to non-contaminated clay.
4. Resistance offered is quite high initially; moderate in between 8-12mm and beyond 12mm resistance offering rate is decreased respeactively for single stone column in non-contaminated, 3% and 6% contaminated clays.
5. Axial load carrying capacity decrease with increase in percentage of hydrocarbon in the clay mass.The hydrocarbon presence in the clay mass react with it and try to change clay engineering properties so compatibility between clay mass and stone column get disturbed and ultimately result in decrement in load carrying capacity of a stone column. Here attempt is made to see the performance of stone column as one of the soil improvement method particularly for hydrocarbon contaminated soft clays with increasing percentage of hydrocarbon and with increase in period of contamination there is a considerable change in index properties (Atterberg's limit) of Hd contaminated calcium bentonite. Decrease in plasticity characteristics of calcium bentonite may prove to be use-full in terms of either swell pressure / swell index but it has not benefited increasingly axial load carrying capacity of stone column.



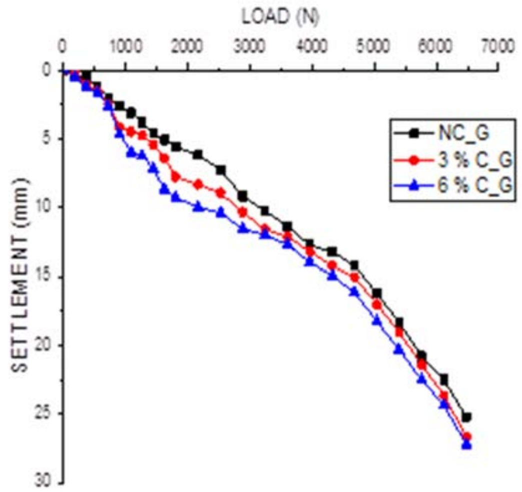


Figure 3(a) & 3(b) P-Δ curve for single column & group columns

3.2 *Water content profile*

From figure 5 it is observed that water content before test and after test has great fluctuation due to the working of the stone column as vertical drains in clay mass. But in hydrocarbon contaminated clays water dissipation is low due to layer formation of hydrocarbon above the clay particles. Vertical permeability decrease with increase in hydrocarbon contamination. The decrease in permeability attributed to the shrinkage of double layer surrounding the particle of clay. Absorption of H_d in clay causes displacement if H^+ ions result decrease in permeability.Calcium bentonite has Ca+2 valance cations on the surface of particles that attracts more water molecules towards it and water particles get attracted towards the basal surface of the clay minerals and therefore it will not release the water easily from the clay mass. If we observed both vertical and horizontal moisture profile of clay mass (along the height of sample and radius of sample) increasing moisture content with increase in depth shows that drainage path is not uniform along the length of stone column though the sample is homogenous and in case of calcium bentonite the zone of influence (taken as per IS 15284) is inefficient in attracting radial water in plain strain conditions.

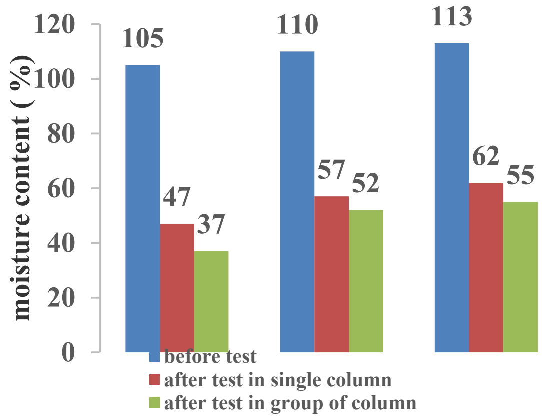


Figure 3. Moisture content profile

Table 4. Shear strength profile

	shear strength profile		
	NC	3%C	6%C
before test	15	15	15
After test single column	22.4	21.5	20.3
After test group of column	25.3	24.2	22.5

3.3 *Shear strength*

Table 4 shows the shear strength variation in the clay mass before and after test. By infusing the stone column in soil mass it sufficiently removes water from it and increase the shear strength. But in H_d contaminated clays due to the hydrocarbon internal slippage increases between the clay particles. During consolidation, the undrained strength and stiffness of the soil increase progressively. But as the percentage of contamination increases for the same contamination period, more and more surface of the clay is covered with hydrocarbon owing to lower mobility of water through the system and this lead to low shear strength value of clay mass containing hydrocarbon as compare to virgin clay mass.

1. In single column test shear strength is improved by 33%, 30%, 26% respectively in NC, 3%C and 6%C clays.
2. In group of column test shear strength is improved by 40%, 38%, 33% respectively in NC, 3% C and 6%C clays.

3.4 Bentonite-hydrocarbon interaction, bentonite-hydrocarbon-stone column interaction

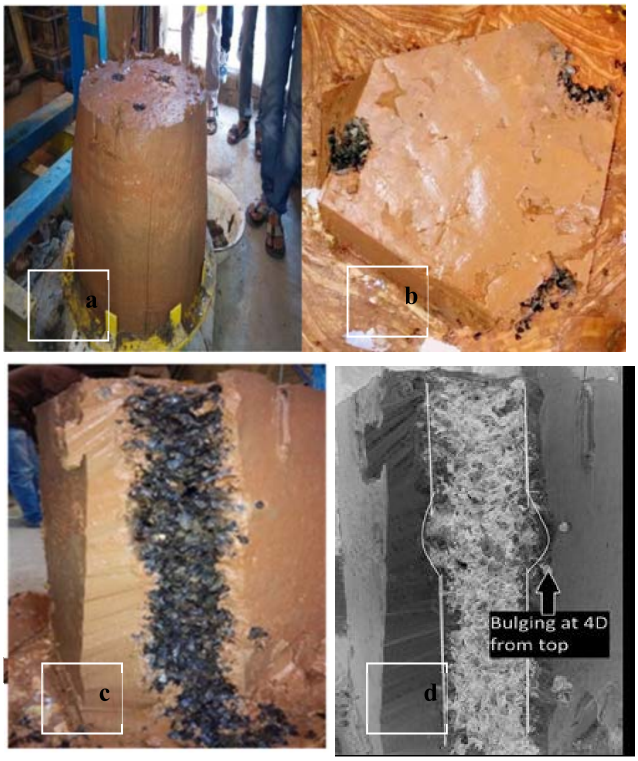


Figure 4. Post test analysis (a) soil after test (b) isometric view of soil mass (c) sectional view of stone column and clay (d) bulging of column in soil mass

i. Due to compressibility of soft mass and dissipation of pore water under constant magnitude of stress the overall height of column is found reduced by 30mm with respect to original height.
ii. If the length of column is equal to or greater than 4D (diameter of column) then it fail by bulging (IS 15284 part-1 2003). Column fails by bulging equal to 2D (10 cm) at the centre of the column.
iii. Calcium bentonite used as clay bed, has high cohesion and adhesion inherently. Such high plastic clay having very low shear strength and stiffness when it comes in contact with water. Such type of soil are susceptible to the marine deposit having problem of high pore water pressure generation.
iv. During the compression test on entire clay bed, soft clay would not give sufficient resistance to carry load, and column angular material will penetrate under the soft clay bed. This will lead to column bulging t certain depth of column.

4 CONCLUSIONS

- Single column tests with an entire unit cell area loaded compare well with the group test results. Hence the single column behaviour with unit cell concept can simulate the field behaviour for an interior column when large number of columns is simultaneously loaded.
- It is remarkably observed that stiffness of soil and stiffness of stone column has vast difference so due to such difference, compatibility between stone column and soil is not form and stone column does not work sufficiently.
- The hydrocarbon contamination leads to decrement in liquid limit as compared to liquid limit of non-contaminated bentonite clay. The mineralogical composition of hydrocarbon (Dodecane) comprises of long chains of carbon-hydrogen atoms, which when comes in contact with water leads to decrease in inter-molecular bond and leads to development of viscous layer over the clay mass, and also hydrocarbon has low density in comparison to water, it tends to float and thus leads to reduction in liquid limit.
- Water is covered by the hydrocarbon particles and it reduces effectively by means of radial consolidation provide by infusion of stone column in it.
- This decrement in load carrying capacity is due to the internal slippage of particle due to the oil contamination and presence of high moisture in the mass, both together reducing the strength of the whole system.
- Axial capacity of column is decreasing in Non-contaminated clay, 3% H_d Contaminated and 6% H_d contaminated clay by 20 % in singular column and 12.5% in group of three column.
- Shear strength is sufficiently improved by inducing the stone column. But as increases the % contamination in clay, shear strength decreases due to the internal slippage of the clay particles.
- The load settlement behaviour of a unit cell with an entire area loaded is almost linear and it is possible to find the stiffness of improved ground.
- Decrease in bulge depth and increase in diameter of bulge have been observed in Non-contaminated clay to 3%, 6% H_d contaminated clays.
- Load resistance offered by stone column with increasing percentage of contamination depends on two aspects. First integrity of stone column (uniform density of stone column throughout its length) and uniform settlement of clay mass compatible with structural rearrangement of gravel under increment of various stress levels. Second is load resistance offered by the stone column is very high in the initial portion of the curve up to 3-5 mm settlement, moderate between 5-10 mm and very low beyond 10 mm in non-contaminated and hydrocarbon contaminated bentonite clay. The effect of lower load resistance with increase in settlement is due to low dissipation rate of pore water even under higher loads because of smear wall created by calcium bentonite and swelling properties of clay.

- Rate of decrease in water expulsion under higher loads with increase in % contamination depicts that rate of inward radial flow of water was decreasing though load was increasing which is even noted in settlement measurements also.

There is a definite impact of both percentage hydrocarbon contamination and periodic contamination on the index and engineering properties of calcium bentonite, though it is stabilize by inducing singular stone column and group of stone columns. This leads us advance assessment of influence of both percentage contamination and periodic contamination on strength characteristics of such marine clays. It is necessary to provide a remedy which will not increase only it load carrying capacity/bearing power but which also reduces differential settlement. This study was an attempt to project stone column as one of the remedy technique for hydrocarbon contaminated clay and to estimate load carrying capacity for various percentages of contamination. It is further observed that behaviour of stone column embedded in calcium bentonite shows very progressive results and can be very well adopted for greater depths of clay deposits. For such hydrocarbon marine deposits especially of calcium bentonite, stone column proves to be most efficient and ecological technique if adopted with proper understanding of bentonite-hydrocarbon-water interaction chemistry.

ACKNOWLEDGEMENTS

The authors are highly thankful to Prof. (Dr) G.P. Vadodariya, Dean, L.D.College of Engineering and Prof. A.R. Gandhi, Head, Applied Mechanics Department, LDCE, Ahmedabad, India for extending research facilities for this project.

REFERENCES

Ambily and Gandhi (2004) "Experimental and Theoretical Evaluation of Stone Column in Soft Clay" Page 201-206, Year of Publish 2004, ICGGE.

Ambily and Shailesh R. Gandhi (2007) "Behavior of Stone Columns Based on Experimental and FEM Analysis" Journal of Geotechnical and Geo environmental Engineering Volume 133 number 4, April 2007, American Society of Civil Engineers.

Bora Mukul C and Dash Sujit Kumar "Load Deformation Behaviour of Floating Stone Columns in Soft Clay" December 16-18, 2010, page 250-255, Indian Geotechnical Conference

Bowles (1988). Foundation Analysis and Design, 4th edition, McGraw – Hill International Editions,New Delhi.

Datye, K.R. and Nagaraju,S.S. (1981). Design Approach and Field Control for Stone Columns, Proc. Tenth Int. Conf. On SMFE., Stockholm, Vol. 3, 637 – 640.

Greenwood, D.A. (1970). Mechanical Improvement of Soils Below Ground Surfaces, Proc. Ground Engineering Conf., Institution of Civil Engineers, London, 11-22.

Hughes, J.M.O. and Withers, N.J. (1974). Reinforcing of Soft Cohesive Soils with Stone Columns, Ground Engineering, Vol.7, No.3, 42-49.

Hughes, J.M.O., Withers, N.J. and Greenwood, D.A. (1975). A Field Trial of Reinforcing Effect of Stone Column in Soil ,Geotechnique, Vol.25, No.1, 32-44.

Ling Zhang and Minghua Zhao "Deformation Analysis of Geotextile-Encased Stone Columns" International journal of geo mechanics (2014), page 04014053(1) - 04014053(10), American Society of Civil Engineers.

Madhav, M.R. (2000).Granular Piles- Recent Contributions. A short term course on Ground Improvement and Deep foundations held at IIT Madras, Dec 2000, MRM1 - MRM38.