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AN EXPERIMENTAL STUDY ON QUARRY WASTE COLUMN WITH AND WITHOUT GEOTEXTILE ENCASEMENT SUBJECTED TO SHEAR LOADING

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ABSTRACT: Stone column may be subjected to shear deformations and lateral translations due to the lateral soil movements in the field. Behaviour of stone column subjected to lateral soil movement is studied by conducting shear load tests. Tests were conducted with and without geotextile encasement having different tensile strength at different spacings. Suitability of using the quarry waste as the column material was also examined. Test results have shown that shear resistance of the soil has increased with inclusion of quarry waste column and further increased further by geotextile encasement. The lateral stiffness of the column also increases by geotextile encasement.

INTRODUCTION

Stone column is a ground improvement technique designed to carry the vertical loads. But in the field there is a chance for the lateral soil movement and as a result lateral thrust will be exerting on the stone column. The pressure from the surrounding soil may cause shear failure in the stone column when the confinement from the soil is not adequate. Consequently, the stone column may undergo lateral translation. An example for lateral soil movement is the case at the toe of embankments (Fig 1). Such a soil movement will exert severe lateral pressure on the stone columns.

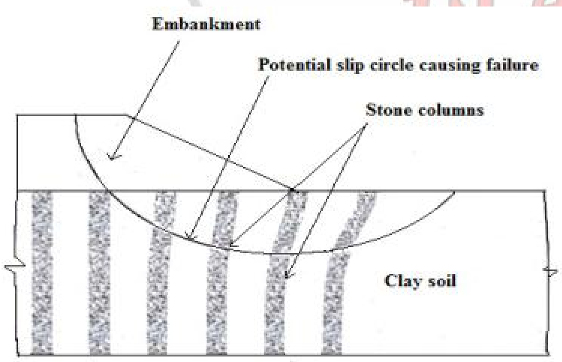

Fig. 1 Lateral thrust on stone columns at the toe of an embankment

If a lateral confinement is provided to the stone column the problems that are caused due to the poor confinement of surrounding soil can be solved. Inorder to impart adequate confinement to the stone column to resist the lateral pressure, geotextile encasement can be provided surrounding the stone column. As the stone aggregates are confined, they can mobilise higher shear strength and the resistance against lateral soil movement can be improved significantly.

In this study, quarry waste is used as the stone column material since it is very cheap and is easily available. Hence the effectiveness of using the quarry waste as stone column material is studied by conducting axial loading test. Thus instead of stone column, the term quarry waste column (QC) is used in the entire study. The effect of using different geotextile for the encasement of the stone column is also studied. Thus the behaviour of nonwoven geotextile encased quarry waste column (NEQC) and woven geotextile encased quarry waste column (WEQC) is also examined.

EXPERIMENTAL STUDY

Materials Used

Soil used for the study was disturbed sample and was collected from a paddy field at Puranattukara, Thrissur at a depth of 1m from the ground level. The soil was initially air dried in open atmosphere prior to the testing. The soil was sieved through 4.75mm sieve to remove the coarser fraction. The soil passing through 4.75mm sieve was used for the entire study. The properties of the soil were determined and are listed in Table 1.

Table 1 Properties of soil

Properties	Values
Specific gravity	2.5
Liquid limit(%)	67
Plastic limit(%)	44
Plasticity index(%)	23
Shrinkage limit(%)	18
Clay(%)	45
Silt(%)	48

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Sand(%)	7
Maximum dry density(kN/m^3)	12.7
Optimum moisture content(%)	33.4

Quarry waste was collected from Thomson Granite Quarry situated at Mulayam, Thrissur. Quarry wastes which passes through 4.75 mm and retained on 425 micron sieve was used as the column fill material for the axial and shear loading tests. The properties of the quarry waste used for the experimental programme were listed in Table 2.

Table 2 Properties of quarry waste

Parameter	Values
Maximum density, $\Upsilon_{d\ max}$ (kN/m^3)	19.73
Minimum density, $\Upsilon_{d\ min}$ (kN/m^3)	16.7
Angle of internal friction, ∅	40°

Woven and Nonwoven geotextile were used for the study. TF1 3200 and PR 15 were the two types of geotextiles used for encasing the quarry waste column. TF1 3200 is a woven geotextile, manufactured from high tenacity, high molecular weight multifilament Polyester yarn. PR 15 is a needle punched nonwoven geotextile. The properties of the geotextiles were listed in Table 3.

Table 3 Properties of woven and nonwoven geotextiles

Properties	TF1 3200	PR 15
Tensile strength MD (kN / m)	≥ 200	9
Tensile strength CD (kN / m)	≥50	10
Elongation MD/CD (%) Tensile	10±2	10±2
Strength @5%Strain (MD) (kN / m)	85	_

Physical Modelling

A rectangular tank of 720mm length, 310mm width and 350mm height was used for the experiment. Three PVC pipes of 50mm diameter were used for making the column. The tests were conducted by varying the spacing of the quarry waste columns. Loading plate used for the two loading tests was having a dimension of 310mm x 310mm. The size of the test tank and the loading plate was selected based on the unit cell concept. The parameters varying in the shear loading tests were spacing between columns and tensile strength of geotextile. The quarry waste columns were formed by placing two columns parallel to the loading plate. To study the suitability of using quarry waste as column material, axial load test was conducted using the same test setup.

Preparation of Soft Soil Bed

To make the soil into a soft consistency, the soil was first mixed with water equal to liquid limit. This forms slurry that was free from any lumps. This slurry was placed in buckets of equal dimensions with proper drainage at both ends. For this, sufficient holes were provided at the bottom of each bucket and then it was filled with 6 mm sized stones upto a depth of 50 mm. Over this a filter paper was provided so as to avoid the mixing of the stone and slurry. Also the slurry does not block the drainage path. Over the slurry, another sheet of filter paper was provided and a thermocol disc was placed above it. Dead weights were provided above it using 150 mm x 150 mm concrete blocks of 9 kg weight to allow consolidation.

Consolidation of clay bed was continued for a period of 2 days until the water content reduced to a soft consistency. By this method, clay beds of uniform moisture content and consistency were obtained throughout the test. Before filling the test tank with the prepared clay, inner surface of the tank was smeared using oil in order to avoid side wall friction. The soil was filled upto a depth of 300mm in the test tank for the two loading tests.

Formation of Quarry Waste Column

Inorder to construct the quarry waste column a PVC pipe having an outer diameter equal to the diameter of the column was used. The quarry waste column were arranged in a triangular pattern for axial loading test, three PVC pipe of 50 mm diameter was placed at spacing of 2 times diameter of column, 2.5 times diameter of column and 3 times diameter of column at the centre of the tank. The quarry waste columns were installed by displacement method, and were extended down to the bottom of the tank.

For encased quarry waste columns, the PVC pipes were encased with geotextiles. The quarry waste columns were extended to the full depth of the soil placed in the tank for a height of 300 mm so that *l /d* ratio (length of the column/diameter of the column) is a minimum of 6, which is required to develop the full limiting axial stress on the column. Around this pipe, clay bed was formed. The clay layer was molded gently by hand to expel air during the process of filling.

PVC pipe was then removed from the bed without causing any disturbance to the clay bed. The quantity of the quarry waste required to form the column was premeasured and charged in to the casing pipe in three layers. Quarry waste was carefully charged into the hole in layers. Each layer was compacted using 12 mm diameter rod to achieve a density of 1.97 g/cc, so that ϕ = 40° corresponding to a relative density of 75%. After charging the first layer of the hole with quarry waste, the PVC pipe was gently lifted up so as to leave the encasement intact in the case of encased quarry waste column. Thus the intrusion of surrounding clay into the quarry waste column or neck formation in the geosynthetic in the case of encased quarry waste column due to the lateral thrust of the surrounding clay can be prevented (Murugesan and Rajagopal 2010). Same method of installation of column was also adopted for shear loading tests, where only two quarry waste columns were constructed parallel to the loading plate at distances of 50mm and 100mm.

Axial Loading Test

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The clay bed was then subjected to strain controlled compression loading in universal testing machine at a strain rate of 1.25 mm / min. Test was conducted up to a maximum settlement of 50 mm in the case of axial loading tests. Settlement was measured using dial gauge and the total load applied was measured using proving ring. The test setup for axial load test is shown in Fig. 1. The axial load test was conducted by using the quarry waste as column material and varying the spacing between the columns as 2 times diameter of quarry waste column, 2.5 times diameter of quarry waste column and 3 times diameter of quarry waste column.

Fig. 2 Test setup for axial loading

Shear Loading Test

The shear loading test was done by placing two quarry waste columns parallel to the loading plate, at spacing of 2D, 2.5D and 3D with and without geotextile encasement at a clear distance of 50mm and 100mm from the loading plate. The clay bed was then subjected to strain controlled compression loading in universal testing machine at a strain rate of 1.25 mm / min. Test was conducted up to a maximum settlement of 25mm for shear loading tests. Stone columns are generally provided below the embankments, retaining walls etc. The chance of lateral soil movement is more near the toe of embankment. Loading in the embankment may not be uniform along their length. So the effect of loading at different locations of the embankment on the columns needs to be studied. To simulate this condition, clear gap is studied. The test setup for shear load test is shown in Fig. 3.

Fig. 3 Test setup for shear loading

The parameters varying in the shear loading tests were spacing between the columns, tensile strength of geotextile and clear gap between the loading plate and quarry waste column.

RESULTS AND DISCUSSIONS

Variation in the Bearing Pressure of Soil When Quarry Waste Column are Installed at Different Spacing

The axial loading test was done by placing the quarry waste columns at spacing of 2 times diameter of QC, 2.5 times diameter of QC and 3 times diameter of QC with and without geotextile encasement. Fig 4 shows the pressure- settlement response of clay with quarry waste column at different spacing

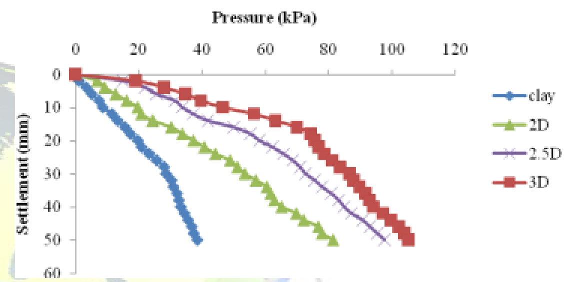

Fig. 4 Pressure- settlement response of clay with and without quarry waste column

It can be observed that the inclusion of quarry waste column have improved the load bearing of the clay bed. This may be due to the densification of the clay bed by the inclusion of quarry waste column. As the spacing increases, the bearing pressure of the soil increases at 50mm settlement. It can be clearly observed that as the spacing increases from 2D to 2.5D, the improvement in the bearing pressure at 50mm settlement is high. But as the spacing increases from 2.5D to 3D, the improvement in the bearing pressure at 50mm settlement is less compared to that from 2D to 2.5D. The difference in the improvement is more at 2.5D. The difference in the improvement achieved between 2.5D and 3D is marginal. Thus it can be said that the quarry waste can be used as a stone column material.

Shear Resistance of Soil at a clear gap of 50mm

Loading was done at a clear gap of 50mm from the quarry waste columns at different spacings for WEQC and NEQC. Fig. 5 shows pressure- settlement response of clay at a clear gap 50mm

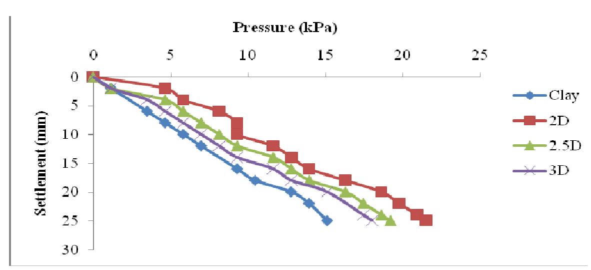

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Fig. 5 Pressure- settlement response of clay with QC at 50mm clear gap

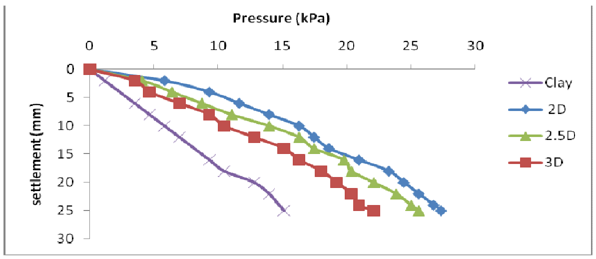

Fig. 6 Pressure- settlement response of clay with NEQC at 50mm clear gap with different spacing

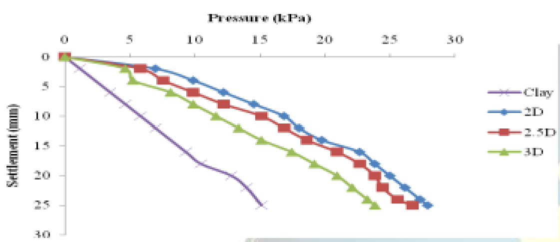

Fig. 7 Pressure- settlement response of clay with WEQC at 50mm clear gap at different spacing

Fig. 5, 6 and 7 shows that the bearing pressure of the soil has improved when the QC was encased with nonwoven geotextile while subjected to shear loading at a clear gap of 50mm. The bearing pressure of the soil decreases with increase in the spacing between the columns from 2D to 3D. But there is only slight variation in the bearing pressure of the soil when the columns are placed at 2D and 2.5D. The bearing pressure of the soil has further decreased when the spacing between the columns increases from 2.5D to 3D. Since the difference in the improvement of bearing pressure between 2D and 2.5D is very small. Variation in the bearing pressure of the soil subjected to shear loading can be attributed to the shear resistance of the soil. It has shown that the shear resistance of the soil increases with the inclusion of the QC. With increase in the spacing of the column, the shear resistance of the soil was found to be decreasing. As the spacing increases from 2D to 2.5D, the shear resistance of the soil has been decreased and it further decreases when the spacing has increased from 2.5D to 3D.

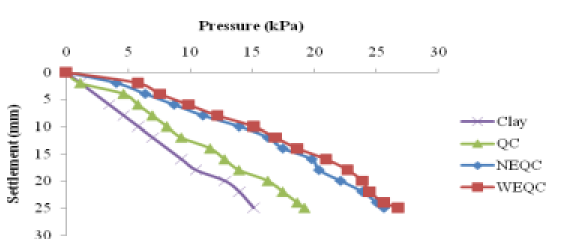

Fig. 8 Pressure- settlement response of clay with and without geotextile encased QC at 2.5D with 50mm clear gap

It can be observed from Fig. 8 that inclusion of QC increases the bearing pressure of the soil subjected to shear loading at 2.5D. The bearing pressure has improved further when it is being encased with a geotextile. The bearing pressure improvement is significant while encasing the QC with the woven and nonwoven geotextiles. However, the improvement in the bearing pressure achieved between woven and nonwoven encased QCs is negligible, it can be said that the tensile strength of geotextile have less effect in the bearing pressure of soil subjected to shear loading.

The bearing pressure of the soil can be expressed as the shear resistance of the soil. Thus the shear resistance of the soil has improved with the inclusion of QC and it has improved further while being encased with a geotextile. The tensile strength of the geotextile has negligible effect on the shear resistance of the soil. This has proved that the QCs require only an encasement to provide a resistance to bulging of column.

Lateral Deflection of Quarry Waste Column at a Clear Gap of 50mm

While applying shear loading to the column, the top end of the column may deflect laterally. The lateral deflection of the QC depends on the extent to which it resists lateral deformation in response to an applied force. This means that the lateral deflection of the QC depends on the lateral stiffness of the column. The lateral deflection at the top end of the QC when subjected to shear loading was measured using the dial gauges at the top of the columns.

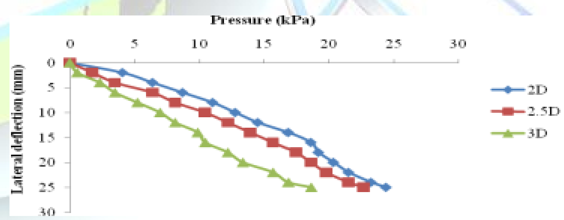

Fig. 9 Pressure vs lateral deflection at the top end of QC at 50mm clear gap

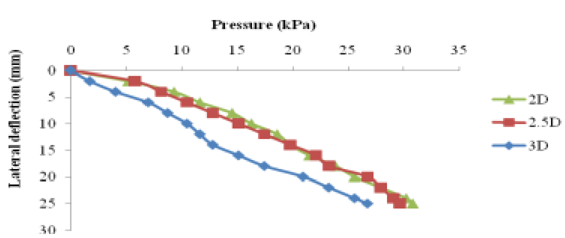

Fig. 10 Pressure vs lateral deflection at the top end of the NEQC at 50 mm clear gap

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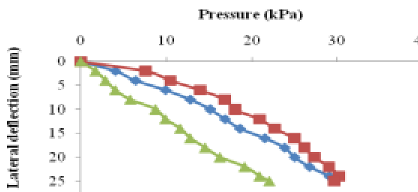

Fig. 11 Pressure vs lateral deflection at the top end of the WEQC column at 50 mm clear gap

It can be observed from Fig. 9, 10 and 11 that the lateral stiffness of the WEQC decreases with increase in the spacing between the columns from 2D to 3D when subjected to shear loading with 50mm clear gap. The lateral stiffness of the column will be higher when the columns are placed at 2D. The lateral stiffness decreases when the spacing of the columns further increases from 2.5D to 3D.

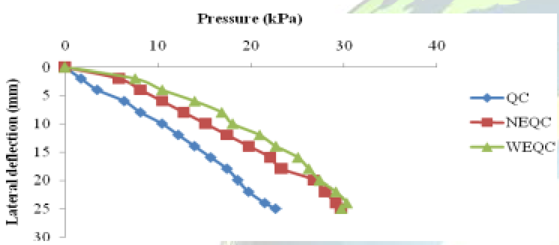

Fig. 12 Pressure vs lateral deflection at the top end of the QC with and without geotextile encasement with 50 mm clear gap

It can be observed from the Fig. 12 that the lateral stiffness of column increases while it is being encased with a geotextile when subjected to shear loading at a clear gap of 50mm. The lateral stiffness of the column is increased when encased with woven and nonwoven geotextile. The lateral stiffness is almost same for WEQC and NEQC. This has shown that the tensile strength of the geotextile has no significant effect in the lateral stiffness of the column

Shear Resistance of Soil at a Clear Gap of 100mm

Loading was done at a clear gap of 100mm at different spacings with and without geotextile encasement.

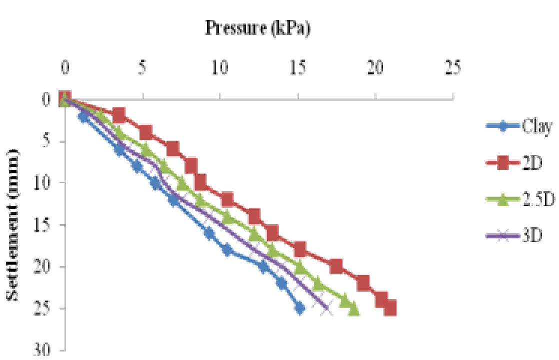

Fig. 13 Pressure settlement response of clay with QC at 100mm clear gap

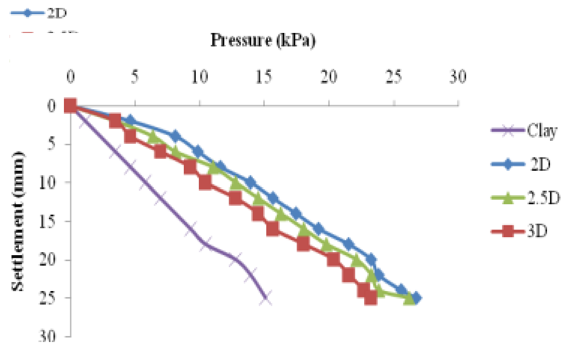

Fig. 14 Pressure settlement response of clay with NEQC at 100mm clear gap

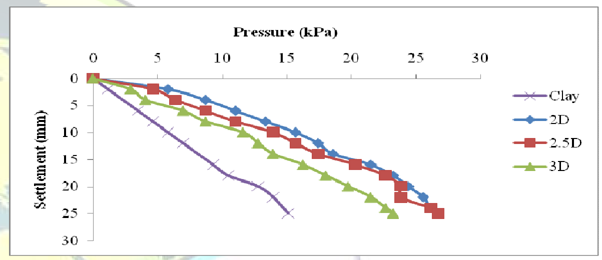

Fig. 15 Pressure settlement response of clay with woven encased quarry waste column at 100mm clear gap

Fig. 13, 14 and 15 shows that the bearing pressure of the soil has improved when the QC was encased with woven geotextile, while subjected to shear loading at a clear gap of 100mm. The bearing pressure of the soil decreases with increase in spacing between the columns from 2D to 3D. But there is only slight variation in the bearing pressure of the soil when the columns are at 2D and 2.5D. The bearing pressure of the soil has further decreased when the spacing between the columns increases from 2.5D to 3D.

The variation in the bearing pressure of the soil subjected to shear loading can be attributed to the shear resistance of the soil. It has shown that the shear resistance of the soil increases with the inclusion of the QC. With increase in the spacing of the column, the shear resistance of the soil was found to be decreasing. As the spacing increases from 2D to 2.5D, the shear resistance of the soil has decreased and it further decreases when the spacing has increased from 2.5D to 3D.

It can be observed from Fig 4.26 that inclusion of QC increases the bearing pressure of soil subjected to shear loading at 100mm clear gap. The bearing pressure has improved further when it is encased with a geotextile. Bearing pressure improvement is significant while encasing QC with woven and nonwoven geotextiles. But improvement in the bearing pressure achieved between WEQC and NEQC

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is negligible. This proved that tensile strength of geotextile have less effect in the bearing pressure of soil subjected to shear loading.

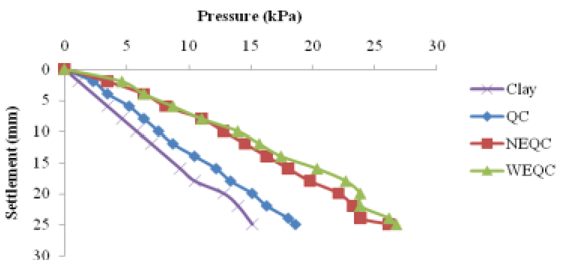

Fig. 16 Pressure settlement response of clay with and without geotextile encased QC at 100mm clear gap

The bearing pressure of the soil can be expressed as the shear resistance of the soil. Thus the shear resistance of the soil has improved with the inclusion of QC and it has improved further when encased with a geotextile. Tensile strength of geotextile has negligible effect on shear resistance of soil. This has proved that QC requires only an encasement to provide a resistance to bulging of column.

Lateral deflection of the column at 100 mm clear gap

Fig. 17shows the pressure vs lateral deflection at the top end of QC placed at 2D, 2.5D and 3D with a clear gap of 100mm from the loading plate.

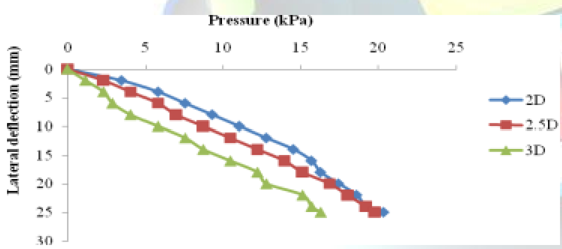

Fig. 17 Pressure vs lateral deflection at the top end of QC at 100mm clear gap

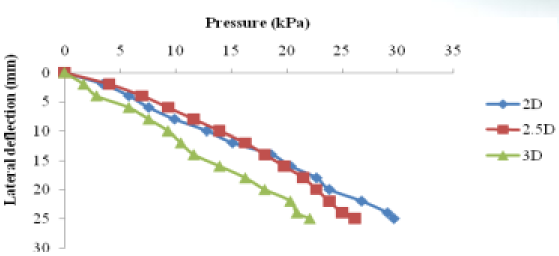

Fig. 18 Pressure vs lateral deflection at the top end of the NEQC column at 100 mm clear gap

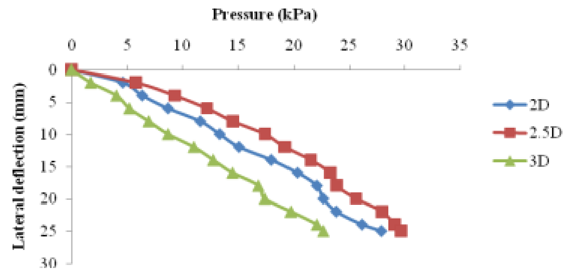

Fig. 19 Pressure vs lateral deflection at the top end of the WEQC at 100 mm clear gap

It can be observed from Fig 17, 18 and 19 that lateral stiffness of the WEQC decreases with increase in spacing between the columns from 2D to 3D when subjected to shear loading with 100mm clear gap. The lateral stiffness of column will be higher when the columns are placed at 2D. The lateral stiffness decreases when the spacing of the columns further increases from 2.5D to 3D. It can be observed from the Fig 20 that the lateral stiffness of the column increases while it is being encased with a geotextile when subjected to shear loading at a clear gap of 100mm.

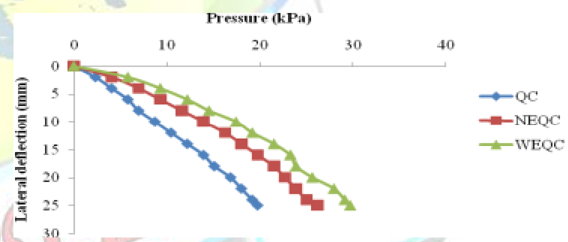

Fig. 20 Pressure vs lateral deflection at top end of QC with and without geotextile encasement at 100mm clear gap

The lateral stiffness of the column is increased when encased with woven and nonwoven type of geotextile. The lateral stiffness is almost same for WEQC and NEQC. This has shown that the tensile strength of the geotextile has no significant effect in the lateral stiffness of the column.

CONCLUSIONS

- Quarry waste can be economically and effectively used for stone column construction
- Shear resistance of the soil has improved with the use of QC. It has increased with the decrease in the spacing between the columns.
- Geotextile encased QC shows better shear resistance than unreinforced QC. WEQC and NEQC has shown similar shear resistance.
- Lateral stiffness of the column was increased with the decrease in the spacing between the columns at 50 and 100mm clear gaps.
- As clear gap increases, the effect of shear loading on the columns decreases.

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