An Experimental Study on Improving the Performance of Silty Soil by Encased Granular Column Using Shredded Tire Chips

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Abstract: Use of stone/granular columns is considered as one of the influential soil-stabilizing methods that can increase the load bearing capacity of soft soil foundations considerably. Recently, it has been reported that the stone aggregate can be replaced by shredded tire chips partially or fully, which will lead to an economical design solution for a granular column. On the other hand, the tire chips are waste materials, and if used for major geotechnical applications; this will not only solve the environmental problems but also result in considerable savings in terms of natural resources thus making the construction method sustainable. This paper presents the results of an experimental study carried out with shredded waste tire chips as a substitute fornatural aggregates and also their effect on granular column behaviour. Typical size ranges of tire chips used in the study were 10 mm × 10mm × 10mm. The aggregates used were passing through 12.5 mm and retained on 10mm sieve. Geogrid encasement, namely, Combi grid was used in experimental investigation. A series of small-scale model tests were performed on ordinary granular column (OGC) as well as granular columns made up of shredded tire chips and aggregates and encased with Combi grid (EGC). All the granular materials were compacted at 90% relative density. The strain rate for all the tests were maintained at 1.2 mm/min. The results of the study indicate that the load-carrying capacity significantly increased even the granular column made of 100% tire chips. It has also been observed that ordinary stone column made of aggregates without encasement can be completely replaced by the encased granular column made of 100% tire chips. However, the load-carrying capacity of encased stone column made of aggregates found to be higher than that of tire chips.

Keywords:granular column, Shredded tire chips, Combi-grid

1. Introduction

Soils with large volume fractions of silt and clay are the most troublesome and challenging to the geotechnical engineers. Silty soils hold the moisture so that it's

very difficult to drain through this. So poor drainage is the most problematic condition with silty soil. Major Geotechnical problems because of silty soil are due to low bearing capacity, low strength, poor drainage, low stiffness, high compressibility and sometimes high liquefaction potential. By considering all these conditions, a suitable and effective ground improvement technique is needed.
So many soil stabilizing methods are available for soft soils. Out of all stabilizing methods, stabilization of silty soil with granular column using geosynthetic encasement found to be most promising both in terms of reliability and cost feasibility. Granular column consists of crushed coarse aggregates of various sizes and mainly aggregates used as a granular material for granular columns.
Large quantities of natural materials such as aggregates etc. are used in the construction of roads, embankments and all other civil engineering structures. Now a days due to lack of these natural materials, there is a need to find suitable alternative material, which will replace these natural materials. Shredded tire chips are the one such alternative material for aggregates which is derived from worn out tires.
Further, due to the provision of geosynthetic encasement to granular columns, which not only increases the stiffness and load carrying capacity of granular columns but also reduces the resulting settlements and liquefaction potential of silty soil. In the present study, geosynthetic namely; Combi-gridwasused as an encasement material.

2. Motivation and Objective

To evaluate the improvement in ultimate load carrying capacity of granular column by shredded tire chips with combi-grid encasement, a series of load test has been carried out.

3. Literature Review

Many laboratory studies of granular column and types of alternative materials available for aggregates have been reported in literature by various researchers. The beneficial effects of provision of geosynthetic encasement in the increment of load carrying capacity of granular column in soft soils have also been reported. Malarvizhi and Ilamparuthi (2004) studied the load versus settlement of soft clay bed stabilized with plain stone columns and geogrid encased stone columns using laboratory scale model load tests and found that the ultimate load bearing capacity of geogrid encased granular column treated soft soil beds are three times that of the untreated bed and ordinary granular column treated soft soil beds are two times that of the untreated bed. Ayothiraman and Soumya (2011) used worn out waste tire chips as an alternative material to stone aggregates in the construction of granular columns. From the experimental results, it is shown that shredded tire chips can be used as replacement of stone chips up to about 50% to 60% in the granular columns which is the economical and eco-friendly solution. Shariatmadari et al. (2017) used three sizes of shredded waste tires (fine, medium and large) as a substitution for gravel materials and investigated their effect on stone columns behaviour. They reported that, replacing 20% of gravel with medium tire shreds (4.75-9.5mm) leads to about 30%

higher value of bearing capacity and high friction angle. Addition of 40% and 60% tire content causes reduction in bearing capacity. Most recently, Mazumder et al. (2018) conducted experimental study on behaviour of geonet encased stone column with tire chips as aggregates and found that, stone column encased with geonet showed an increase in load carrying capacity by about 35% as compared to columns made of 100% stone aggregates without encasement.

4. Test Materials

4.1 Silty Soil

Silty soil used in the present study was collected from Seraikela, Kharsawan district, Jharkhand. The silt was transported to laboratory in Jamshedpur using sealed plastic bags. The properties of silty soil were determined by standard test procedures as stipulated in the relevant IS Code of practice.Fig.1 shows the grain size distribution curves for silty soil used in the study and Table 1 summarizes the basic properties of silty soil respectively.

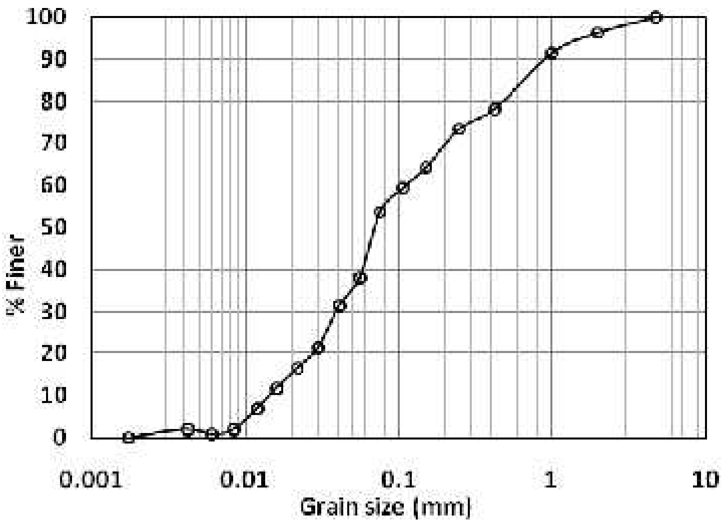

Fig. 1 Grain size distribution of silty soil used in the study

Table 1 Properties of silty soil

Properties	Value	Test code
Specific gravity	2.58	IS 2720-Part 3
Liquid limit	36.2%	IS 2720-Part 5
Plastic Limit	28.33%	IS 2720-Part 5

Plasticity index	7.87	IS 2720-Part 6
Soil classification	MI	IS 2720-Part 4
O.M.C.	19.55%	IS 2720-Part 7
M.D.D. (g/cc)	1.64	IS 2720-Part 7
Free swell index	4.17%	IS 2720-Part 40
Fines content	53.72%	IS 2720-Part 2

4.2 Aggregates

The aggregates required for this study was collected from Jamshedpur. The aggregates passing through 12.5mm sieve and retainedon10mm sieve was used in the study. Table 2 summarizes the basic properties of aggregates respectively.

Table 2 Properties of aggregates

Properties	Value	Test code
Specific gravity	2.73	IS 2386-Part 3
$\gamma_{d\ max}$ (kN/m^3)	16.40	IS 2386-Part 3
γ_{dmin} (kN/m^3)	14.60	IS 2386-Part 3
Relative density (%)	90.00	IS 2386-Part 3
γ_d (kN/m^3)	16.20	IS 2386-Part 3
Impact value (%)	7.80	IS 2386-Part 4
Crushing value (%)	13.61	IS 2386-Part 4
Flakiness Index	21.64	IS 2386-Part 1
Elongation index	19.08	IS 2386-Part 1

4.3 Shredded tire chips

The derived waste tire chips were obtained by manually cutting waste tires. Derived shredded tire chips of 10mm × 10mm × 10mm made from worn-out tires have been used in this study. The tire chips required for the study was supplied by M.A. Tire shop, Dimna, Jharkhand.The basic properties of tire chips are presented in Table 3.

Table 3 Properties of shredded tire chips

Properties	Value
Specific gravity	1.14
$\gamma_{d\ max}$ (kN/m^3)	7.40
γ_{dmin} (kN/m^3)	5.98
Relative density (%)	90.00
γ_d (kN/m^3)	7.23
e_{max}	0.91
e_{min}	0.54

4.4 Combi grid

Combi-grid encasement is the next generation of geosynthetic reinforcement products. Combi-grid delivers reinforcement, filtration, separation and drainage in one composite material. Combi-grid geogrid is mainly used in soft soils where soil reinforcement is in combination with separation and filtration is needed. It's very quick and easy to install and it has very high radial secant stiffness value. The combi-grid used in this study was supplied by K.K. Suppliers, Kolkata. Table 4 summarizes the mechanical properties of combi-grid used in the study.

Table 4 MechanicalProperties of shredded tire chips

Properties	Value
Material type	Polypropylene
Standard roll width	4.75m x 100m
Tensile strength (kN/m)	> 30
Elongation	Nil
Ageing	100 years
UV Resistance	80%
Seam strength (kN/m)	3
Aperture size	32mm × 32mm

5. Test setup

A cylindrical tank with internal diameter 252 mm and height of 300 mm was fabricated as per (s/d) ratio of 4 and used as a model tank. The inner diameter of the test tank was taken as the diameter of unit cell as per triangular laid granular columns. The diameter of the granular column was taken as 60mm and all tests were conducted on that granular column. The tanks were made of 3 mm thick galvanized steel sheets. The bottom end was sealed and top end was kept open. Metallic handles were provided for easy handling of tank. The complete test apparatus used in the present study is depicted in Fig.2.

All the tests were conducted with length to diameter ratio (l/d) as 4. Silty bed was prepared up to height 240mm and granular column installed at the centre and vertical load was applied over a 60 mm diameter steel model footing which is equal to the diameter of the granular column. The footing was placed on the prepared granular column and the tank was positioned concentrically under the load cell. A sand layer of thickness 3 cm was placed on silty bed around the footing in order to jacket the footing and to prevent it from premature tilt.

Fig. 2 Test apparatus used in the experimental study

6. Preparation of test specimen

According to the stone column code IS:15284 (Part-1)-2003**,** this technique is suitable for soft soils like silt and clay which is having undrained shear strength is in the range of 7.0 to 50kPa. This technique is not suitable for sensitive soils which are having sensitivity greater than or equal to 4.

A series of unconfined compressive strength tests were conducted on silty soils starting from optimum moisture content 19.55% to up to 31% where undrained compressive strength of soil is 42kPa at optimum moisture content (19.55%) and 8.5kPa at 31% water content and maintained same 31% water content throughout the granular column experimental work.

6.1 Preparation of silty bed

Soil was crushed using hammer.The required amount of water (31%) was added to oven dried soil and mixed well to form a smooth paste without any lumps. The soil paste was kept thematically sealed in an airtight polythene bag for 48 hours for even distribution of moisture.The inner wall of the tank was cleaned and depth markers were marked at every 3cm interval. The soil paste was transferred to the test tank in layers of 3cm each. The amount of soil taken for each layer was equal to the weight of soil required to achieve the needed bulk density. The procedure was continued in layers of 3cm to a total height of 24cm. After completion, the top surface was smoothened out using a steel straight edge. Care was taken so as to not disturb the density at the top.

6.2 Mixing of the Tire chips and Aggregates

The mixing of aggregates and tire chips are done by volume batching. Since the weights or densities of tire chips and aggregates vary by large extent, we adopted volume batching. The mix proportions used in the analysis are 100% AGG (100% aggregates), (50% TC+50% AGG) and 100% TC (100% Tire chips).
The mix proportion of (50% TC+50% AGG) is as follows.
Weight basis for (50% TC+50% AGG)

%TC = $\frac{5}{50}$ = 50%

Volume basis for (50% TC+50% AGG)

%TC = $\frac{\frac{W_{tc}}{G_{tc}}}{\frac{W_{tc}}{G_{tc}}+\frac{W}{G}}$ = $\frac{\frac{50}{1.14}}{\frac{50}{1.14}+\frac{50}{2.73}} = 70.5$

From above calculations it is known that, the tire content of 50% by weight is equivalent to 70.54% by volume.

6.3 Installation of ordinary granular column

All the granular materials (Aggregates, Tire chips) were cleaned and dried in oven. The dry weight of aggregates and tire chips required to achieve 90% relative density was determined. Dry aggregates material except tire chips were weighed out and soaked in water for 24 hours. The soaked material was surface dried with a towel.
Granular column was installed by replacement method. A seamless steel pipe with outer diameter equal to granular column diameter was selected. The driving end of the pipe was sharpened with a bevel edge on the outer surface. The pipe was then inserted at the center of the prepared soil bed until it reached the bottom of the cylinder. The silt inside the cylinder was scooped out using a specially fabricated metallic scoop.
We know the total volume of the cylinder. The total mix proportion is divided into eight equal parts for each 3 cm height based on volume basis. The calculated amount of surface dried granular material was transferred into the pipe in layers of 3cm thick and compacted with a tamping rod. The depth marking on the inside of steel pipe was used as reference for tamping. After tamping, the pipe was raised in stages in such a way that there is an overlap of 1cm. The procedure was repeated and granular column was installed in stages till the required height was reached. Because we done on this mixing proportion on a small-scale apparatus, with proper care, we can control the segregation of tire chips and aggregates. After installation, the tank was wrapped with airtight polythene bag for 48 hours so that silt regained its lost strength caused by disturbance during installation of granular column.

6.4 Installation of geosynthetic encased granular column

A steel pipe with diameter equal to that of the granular column was used as template to make the encasement of the right dimensions. The geogrid encasement was prepared by cutting the Combi grid and wrapping tightly around a steel pipe with diameter equal to that of the granular column. The seam end was stitched with face to face prayer seam single stitch. The pipe was then removed to obtain the encasement. A strap was attached to one end of the encasement. When the granular material was charged into the granular column, the strap anchored and locked the encasement in position.

6.5 Testing methodology

The silty bed has been prepared with required consistency found from the series of unconfined compressive strength. The test cylinder was placed in digital CBR machine for carrying out the load vs settlement analysis. The loading was applied at a constant rate of 1.2 mm/minute. The load applied on the granular column was measured through a calibrated load cell. The settlement was measured using a calibrated LVDT attached to the cylinder. The test was continued up to failure within the granular column or at the predefined amount of displacement. At the end of each load test, moisture content and dry density need to be determined so as to maintain the standard conditions throughout the investigation.

6.6 Test variables

Two different series of tests (A and B) were carried out on granular columns. Test series A carried out on ordinary granular column and test series B carried out on Combi-grid encased granular column. The undrained shear strength of silty soil was determined by unconfined compressive strength. All the tests were carried out on silty soil at 31% moisture content and at relative density of 90%. All the model tests were conducted on cylinder with spacing to diameter ratio 4 and a total of 7 model tests were conducted in this investigation.

7. Results and discussions

The load versus settlement behavior of granular columns observed from two test series are presented in Figs.3-5.The load-settlement behaviour of ordinary granular column with varying percentages of tire chips and aggregates without encasement has been presented in Fig. 3. From the graph, itcould be observed that, the load carrying capacity is significantly varied with change in mix proportion. So, with the application of granular column, load carrying capacity increases significantly. From the results, it is also observed that, the ultimate load carrying capacity of ordinary granular column decreased by 20 to 40% with increasing percentage of tire chips.It is also observed that the load carrying of column can be significantly increased with provision of combi grid around the granular column (Fig.4). This can be clearly seen from Fig. 5. The presentence increase in the performance of granular column with different combination is discussed through efficiency factor in the following section.

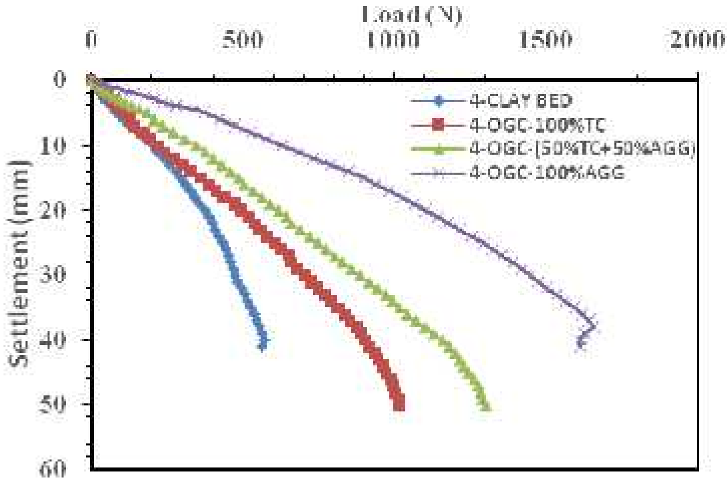

Fig. 3 Load-settlement behavior of ordinary granular column without encasement

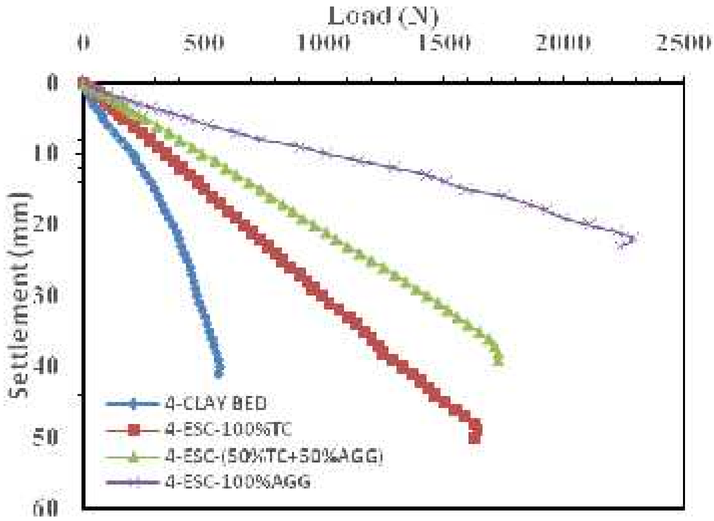

Fig. 4 Load-settlement behavior of combi grid encased granular column

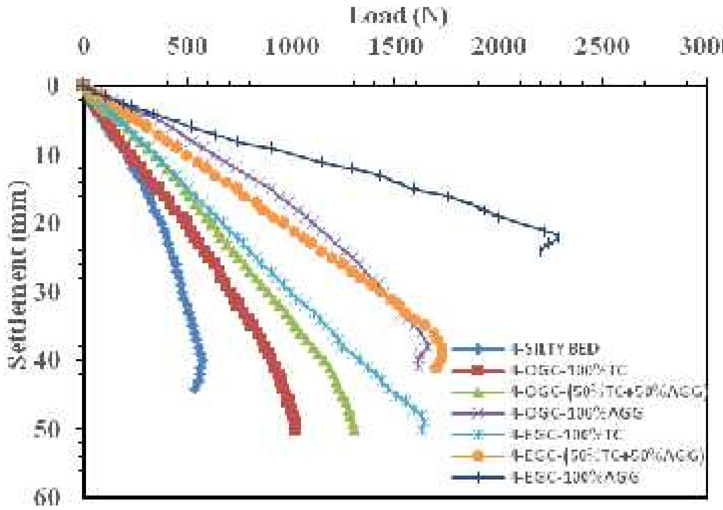

Fig. 5 Load-settlement behavior of both ordinary and combi grid encased granular column.

The variation of efficiency for different mix proportion of aggregates and tire chips and types of granular columns (OGC and EGC) has been presented in Fig.6.Afactor "efficiency" was given by Ayothiraman and Soumya [7], which is used to establish the relationship between optimum percentage of tire chips that can partially replace aggregates in the granular column. Efficiency is defined as a factor which is ratio of load carrying capacity of either OGC or EGC made of any mix proportion to the load carrying capacity of OGC made of 100% aggregates.From the graph it could be concluded that, the efficiency of encased granular column is found to be higher than 1.0 for up to 50% tire content and remains close to 1 up to 100% tire chips content.

This demonstrates that the percentage of tire chips that can replace aggregates lies in the range of 50% to100% using combi grid encasement. The efficiency factors were calculated at the peak settlements of individual mix proportion. The peak settlement for 100% tire chips would be 49mm, 100% aggregates would be 22mm and (50% tire chips and 50% aggregates) would be 39mm. The efficiency reported based on model tests conducted on 60mm diameter columns made of different mix proportions. So, with the help of combi-grid encasement, the efficiency of granular column could be enhanced. The efficiency of ordinary granular column reduced to 80% up to 50% tire chips content and reduced to 60% up to 100% tire chips content.

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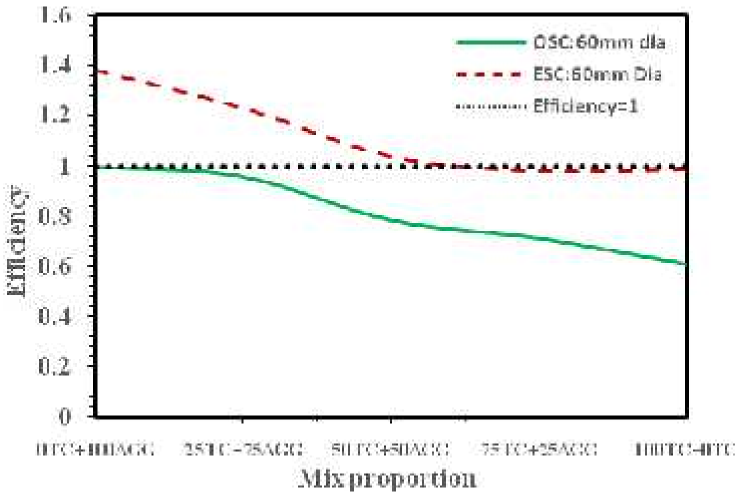

Fig. 6 Variation of Efficiency with Mix Proportion

8. Conclusions

From the above model load tests, the following can be concluded.

1. The load carrying capacity of ordinary granular column can be improved significantly by providingCombi grid encasement.
2. From the results of 10 mm tire chips and 10mm aggregates with different mix proportions, it is found that the ultimate load capacity of ordinary granular column decreased by 20 to 40% with increasing percentage of tire chips.
3. Encased granular column made up of 100% tire chips exhibits load carrying capacity very close to that of ordinary granular column made up of 100% aggregates.
4. The efficiency of encased granular column is found to be higher than 1.0 for up to 50% tire chips content and remains close to 1.0 for 100% tire chips content. This demonstrates that the percentage of tire chips that can replace aggerates lies in the range of 50% to100% using combi grid encasement.

References

1. Ambily and Gandhi(2004).“Experimentalandtheoreticalevaluation ofstone column in soft clay”.Evaluation ofStoneColumn in Soft Clay.
2. Murugesan and Rajagopal(2006). “Geosynthetic-encasedstonecolumns: numerical evaluation”.Geotextiles and Geomembranes,24(6), 349-358.
3. Murugesan and Rajagopal (2008). “Shear load tests on stone columns with and without geosynthetic encasement”. *Geotechnical Testing Journal*, Vol. 32, No. 1, 2009, pp. 76-85
4. Gniel and Bouazza (2009). Improvement of soft soils using geogrid encased stone columns. Geotextiles and Geomembranes, 27(2009), 167-175
5. Yoo (2010).“Performance of geosynthetic-encasedstonecolumnsin embankment construction: numerical investigation”.*Journal of Geotechnical and GeoenvironmentalEngineering*,*136*(8), 1148-1160.
6. Malarvizhi and Ilamparuthi(2010).“MechanismofGeogridEncased Stone Column”.IGS Mumbai Chapter&IIT Bombay, 949-952.ASTM D6270-08(2012) Standard Practice for use of scrap tires in civil engineering applications.
7. Ayothiraman and Soumya (2015). Model tests on the use of tire chips as aggregate in stone columns. Proceedings of the institution of Civil Engineers- Ground Improvement, 168(3), 187-193.
8. IS 15284 (Part-1) 2003 Design and construction for ground Improvement guidelines-part 1 (stone columns). Bureau of Indian Standards. New Delhi.
9. IS 2720-14: Methods of test for soils, Part 14: Determination of density index (relative density) of cohesionless soils. Bureau of Indian Standards. NewDelhi.
10. IS 2720-15: Methods of Test for Soils, Part XV: Determination of Consolidation Properties. Bureau of Indian Standards. NewDelhi.
11. IS 2720-17: Methods of test for soils, Part 17: Laboratory determination of permeability. Bureau of Indian Standards. NewDelhi.
12. IS 2720-2: Methods of test for soils, Part 2: Determination of water content. Bureau of Indian Standards. New Delhi.
13. IS 2720-29: Methods of Test for Soils, Part 29: Determination of Dry Density of Soils In-place by the Core-cutter Method. Bureau of Indian Standards. NewDelhi.
14. IS 2720-3-1: Methods of test for soils, Part 3: Determination of specific gravity. Bureau of Indian Standards. New Delhi.
15. IS 2720-36: Methods of test for soils, Part 36: Laboratory determination of permeability of granular soils (Constant head). Bureau of Indian Standards. NewDelhi.
16. IS 2720-4: Methods of test for soils, Part 4: Grain size analysis. Bureau of Indian Standards. NewDelhi.
17. IS 2720-40: Methods of test for soils, Part 40: Determination of free swell index of soils. Bureau of Indian Standards. New Delhi.
18. IS 2720-5: Methods of test for soils, Part 5: Determination of liquid and plastic limit. Bureau of Indian Standards. New Delhi.