Consolidation of Ground by Vertical Rope Drains

by

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Introduction

For improving the bearing capacity of soft strata preloading of ground has been used since long. But in the case of clayey soil strata of low permeability the gain in shearing strength is at a very slow rate and the loads should remain in position for long periods. For quicker consolidation, sand drains, known as sand piles also has been in use for quite some time. They accelerate the process of consolidation by providing easy drainage path. The first reported example of sand drains is on an-Fransico Oakland Bay Bridge (Porter, 1936). The installation of sand-drains is normally done by closed end driven pipes which are withdrawn after filling in the sand. The drawbacks of the process are the large scale handling of sand which is very often required to be brought from long distances, reduction in drainage efficiency known as 'smear effect' and shear failures in the event of rapid preloading.

To replace the sand drains there has been the development of cardboard drains on which the first large scale experiment was conducted in Sweden in 1937 (Kjellman, 1948). The section of these drains was 100 mm × 3 mm and the installation was at much closer spacing (De Beer et al, 1974) than the sand drains. Various natural and synthetic materials are in use for making the drains of this type. The shortcomings of the process in Indian context are highly sophisticated and patented techniques of manufacture and installation and initial heavy investments.

In India another version of sand drains, known as 'sand wicks' was developed (Dastidar et al, 1969). The sand wicks formed by filling sand in long cylindrical hessian bags of about 65 mm diameter were installed with the help of 100 mm diameter casing pipe. Similar to cardboard wicks the principle utilised in sandwicks was that the effect of drain diameter on degree of consolidation was only a nominal one as compared to the spacing of drains (Leonard, 1962, Younger, 1968 and Rao et al, 1971). The driving was simpler but other shortcomings of sand drains still there. Further, the sandwicks had been reported more susceptible of a loss in their efficiency (Subbaraju et al, 1973).

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The paper is open for discussion till the end of October 1977.

Rope Drains

To overcome various shortcomings of the known processes and keeping in view the fact that closer spacing of drains is advantageous 'rope drains' were developed at the Central Building Research Institute, Roorkee, (Dinesh Mohan et al 1972). The material used was coir fibre which is a byproduct abundantly available in India. The coir is durable and strong in underwater conditions. The coir fibre is woven in the form of a long strip of mat about 150 mm wide and 10 mm thick and then rolled to give a hollow cylinderical tube, Figure 1, which is flexible like a rope. The outer effective diameter of

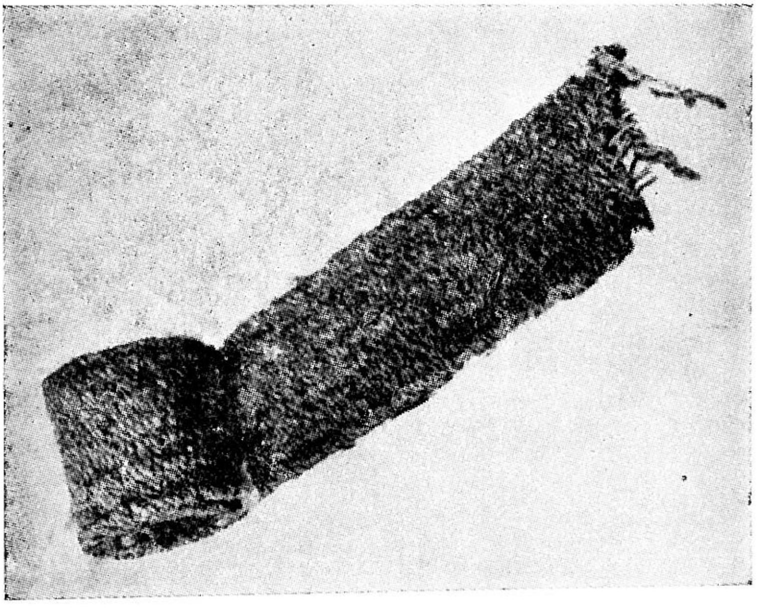

FIGURE 1(a): Coir mat strip

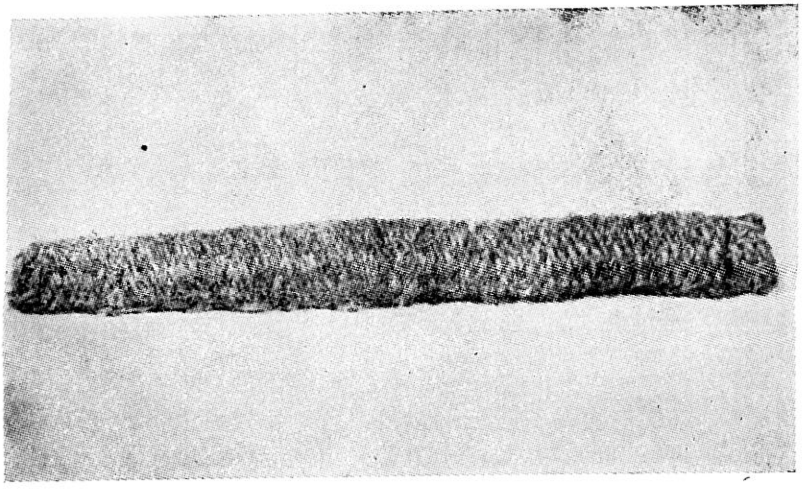

FIGURE 1(b): A piece of drain

the rope drain is about 70 mm and unlike sand drains and wicks, there is a continuous hollow space at its centre longitudinally.

Water draining efficiency of these drains is very good. Laboratory tests on coir fibre packed to a dry density of 0.5 gm per cu. cm showed permeability value of about 3×10^{-2} cm/sec. The coefficient of permeability of this order is comparable to that of clean sands (Terzaghi and Peck, 1967) and can be considered an effective substitute for sand used in sand piles. The permeability of treated card-bored drain is of the order of 10^{-5} cm/sec only (Kjellman, 1948).

For ascertaining the behaviour of rope drains in contact with consolidating soft soil laboratory tests were carried out in a triaxial cell. The soft clay was in direct contact with the circular coir drain and was contained in a rubber membrane. (Figure 2). The soil used in the experiment was

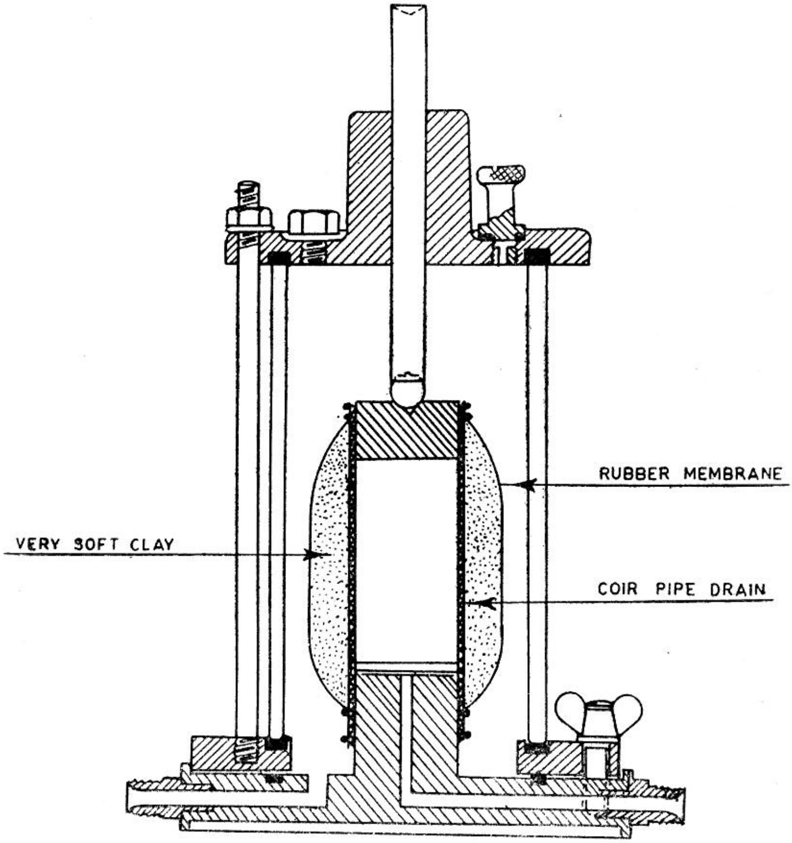

FIGURE 2. Triaxial cell test set up for coir pipe drain

of liquid limit 49 and plasticity index 27. The water content was close to liquid limit. A cell pressure of about 1.5 kg/cm² was applied which compressed the soft soil and led to its water being squeezed through the coir drain. It was observed that the clay did not penetrate beyond a thin skin on the out side of the coir drain and only clear water emerged on the other side. It was therefore concluded that under normal soft ground conditions, coir drains will prove satisfactory for rapid consolidation.

Field Trial

A full scale field trial was carried out at salt lake in Calcutta. A total number of 56 rope drains were installed in a square grid pattern of 8×7 in an area of 11.0 m $\times$ 12.8 m. The spacing of drains was about 1.83 m (Figure 3).

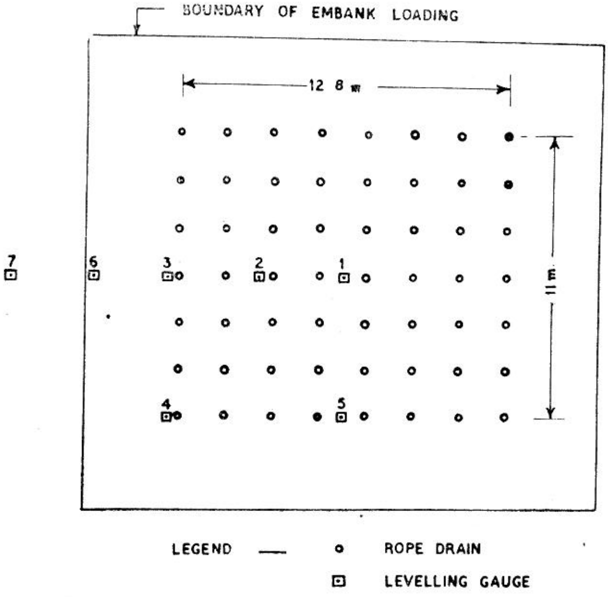

FIGURE 3. Layout of drains and gauges

The rope drains were installed by driving a 8 cm diameter pipe having a loosely fitting conical cast iron shoe at its bottom. Before driving the casing one end of the rope drain was securely tied to the hook in the conical shoe and the rope made to pass through the casing pipe of predetermined length. The driving head was suitably modified by providing a window on side so that rope drain is not damaged during driving. A 500 kg hammer operated by a rope and winch arrangement was used.

When the driving to the desired depth was over, the casing pipe was withdrawn, leaving conical shoe and the rope drain attached to it in position. The driving operation was simple and an ordinary tripod with a suitable winch arrangement was found adequate to install 70 mm diameter rope drains to 12.2 m depth. During an eight hours working five drains could be installed.

The soil strata consisted of a top layer of about 2 m poorly graded fine to medium sand followed by about 3.5 m of silty clay (*CL*) which was underlain by silty clay layers of higher plasticity (*CH*). At about 11.5 m depth the strata was stiff silty clay having some kankar. The bore logs and the penetration test data are shown in Figure 4 and other properties are summarised in Figure 5. It may be noted that silty clay stratum between 5 m and 11 m is generally soft with moisture content between liquid and plastic limit values. As the penetration resistance starts

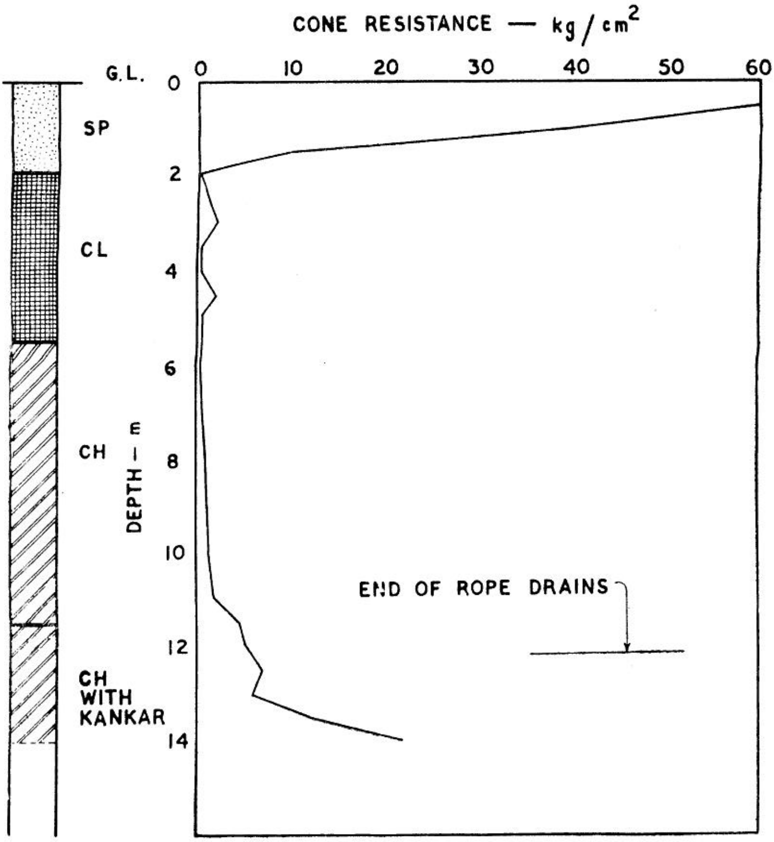

FIGURE 4. Bore log and static penetration resistance

improving steadily after 11 m, a depth of 11.2 m was decided for installing the rope drains.

After installation of drains the area was loaded (Figure 6) by sand embankment and a height of 3.75 m was achieved in 20 days (Figure 7). The final embankment loading gave a pressure intensity of 0.5 kg/cm². The base of the embankment extended beyond the boundary line of rope drains by about 2 m.

For recording the progress of settlement five level points were established at ground level within the rope drain area and two were outside (Figure 3). The level points consisted of an iron base plate of 30 cm $\times$ 30 cm to which a 20mm diameter conduit was attached and was sleeved by a 50 mm diameter pipe to avoid direct contact with the soil. Figure 3 shows a view of the embankment along with the levelling points. Similar arrangement has been used by other workers (Mehra and Natarajan, 1962). The reference datum was a 6 m high G.I. pipe fixed to an underreamed pile of 14 m depth at about 10 m away from the embankment. The levels were taken by a water tube level. As the levelling points were high above the embankment, an improvised bamboo staging was erected to support the

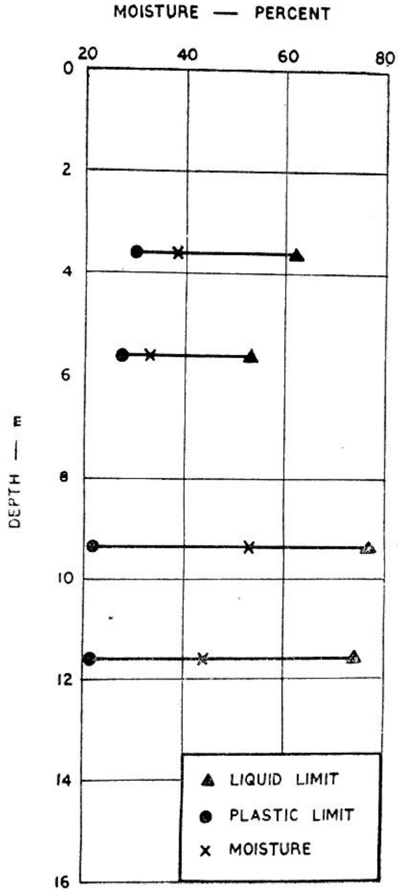

FIGURE 5. Soil properties

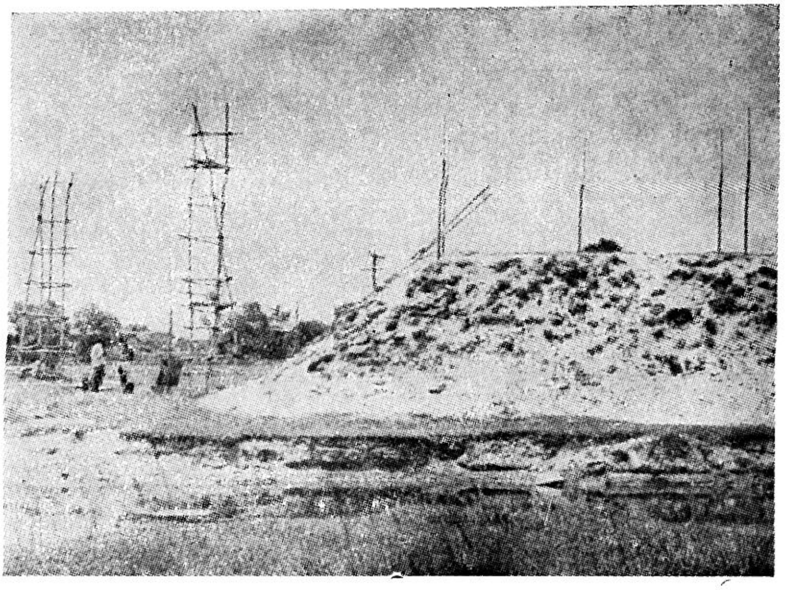

FIGURE 6. A view of embankment

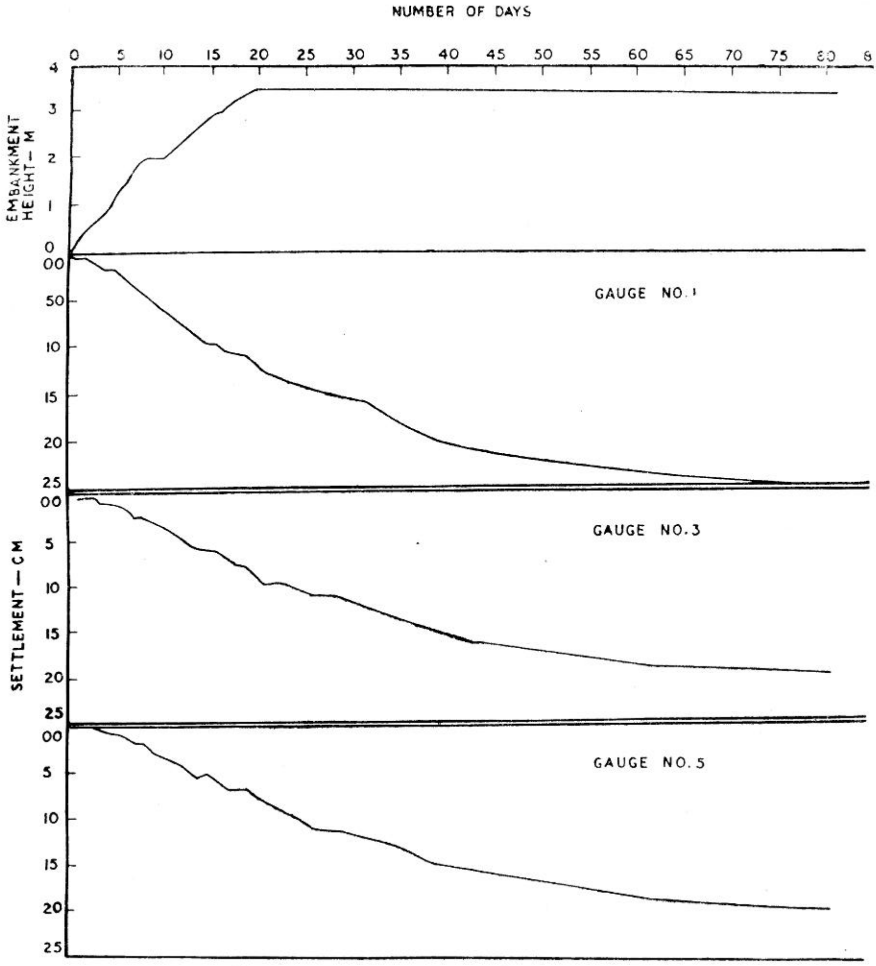

FIGURE 7. Progress of loading and settlement

water reservoir of the water tube level. The progress of settlement recorded at levelling point nos. 1, 3 and 5 is shown in Figure 7.

Discussion

For the layout of vertical drains two types of grid patterns, hexagonal and square are in practice. The hexagonal grid is said to be the most economical one (Barron, 1948). However, it is not a very important advantage (Kjellman, 1948). From practice it seems that while the sand drains are installed in a hexagonal grid, the small size drains like card board drains and sand wicks have been provided in a square grid. In our experiment on rope drains a square grid at 1.83 m spacing was adopted. The effective radius of influence zone was 1.03 m as the effective radius was 0.564 times the grid spacing (Younger, 1968).

The installation of drains by driving a pipe and its subsequent withdrawl can cause remoulding of the soil thereby reducing its permeability which also is known as 'smear effect' (Barron, 1948; Richart 1957). Its effect is indirectly accounted for by considering a reduction in the well diameter and as an approximation it is said to be equivalent to halving the well radius (Leonard, 1962). Other workers (Rao and Rao, 1973) too have focussed attention on this aspect. In this context, as far as the rope drains are concerned, it may be noted that these are comparatively smaller diameter drains, (70 mm), and installation is done by a 100 mm diameter pipe. Hence, remoulding will be much less. Also the permeability of coir mat is very high and as shown by laboratory tests it functions as a draining material efficiently. The effect of smear may be pronounced in the case of distinctly horizontally layered soils. In clayey soils there is likely to be little effect on permeability (Kjellman, 1948). In view of these, it is felt that there is no need to consider smear effect in the case of rope drains.

For vertical drains theoretical solutions have been advanced for equal vertical strain and free strain conditions. In the latter case the soil surrounding the drains consolidates faster than the soil away from it. As has been stated earlier, rope drains are made of a coir mat having a hollow space all through their length. These are also flexible and are not likely to attract a greater intensity of load compared to the surrounding soil. The expected settlements will therefore be uniform and the case of equal vertical strains can be reasonably assumed to apply. It may be further noted that for ratios of effective diameter to drain diameter greater than 5, very close agreement is obtained between the equal strain and free strain cases (Younger, 1968). In the present case this ratio in about 30 and, consequently, the significance of these two conditions is not important.

The consolidating strata which will be significantly effected by rope drains lies between 2.0 to 12.2 m as the strata are comparatively much softer within these depths and top 2.0 m is sand. On the basis of compression index values which ranged from 0.24 to 0.79 the estimated total settlement of the 10.2 m clayey strata under an intensity of embankment loading of 0.5 kg/cm^2 at the centre is 28 cm. The observed settlement (Figure 7) after 81 days from the start of loading is 25 cm. The time-settlement curve has reached an almost asymptotic stage at this settlement which is about 90 per cent of the expected total settlement.

For calculation of settlement with the use of rope drains the charts developed by Barron (1948) relating time factor and degree of consolidation for various ratios of effective radius to drain diameter have been used.

The radius of well diameter (r_w) is 3.5 cm, the effective radius of influence zone (R) is 1.03 m. Hence the ratio $R/r_w=n$ is 29.5 (say 30). From laboratory consolidation tests the average value of coefficient of consolidation in vertical direction (c_v) was estimated to be 4.046×10^{-4} cm^2/sec. The ratio of horizontal to vertical permeability was taken about 2.3.

The degree of consolidation of three dimensional flow U, vertical flow U_v and radial flow U_r were considered (Carillo, 1942) related as

$$1-U=(1-U_v)\,(1-U_r)$$

In the present case the degree of consolidation of three dimensional flow, U, is 90 percent. By assuming various values of U_v, by trial and error, it can be shown that in the present case of $R_w=30$, $C_{vr}/C_v=2.3$, $R=1.03$ m, depth of strata $(H)=10.2$ m and $U=90$ percent the contribution by vertical consolidation is reflected by U_v of 13 percent only. If on the other hand 13 percent of the total consolidation were required to be achieved under the present intensity of loading without the use of drains, the time required will be about 400 days against the actual time 71 days. It is considered that full loading becomes effective after 10 days as there is almost linear increase upto 20 days (Figure 7). To realise 25 cm settlement without rope drains which is 90 percent of final expected, therefore a period of many years will be required. Thus the efficacy of rope drains for quicker settlements is obvious.

The gauge no. 6 near the foot of embankment and no. 7 at about 3 m away from it (Figure 3) did not show any heaving of the ground, which indicates that there was no lateral flow of the soil.

An analysis of cost showed that the major part of the cost was towards the loading and unloading of the soil for the embankment. In this trial the ratio of the cost of installation, the cost of material and the embankment was 1:2:9. In cases where the embankment loading was not required to be removed, such as for highway embankments, the cost of the last item will be almost halved.

Concluding Remarks

Laboratory experiments and field trial have shown that the rope drains made by rolling a coir strip have positive advantages over conventional sand drains and other types of vertical drain. The material used is highly permeable and the central hollow space ensures uninterrupted passage for drainage. The smaller diameter and lighter weight permits easier handling and driving. The flexibilty and strength safeguards against loss of continuity in an event of shear failure by excessive embankment loading. Closer spacing is possible to easy driving and it leads to increasing the efficiency of the process. The fabrication of rope drains as also their installation are simple and quick.

Acknowledgement

The study was carried out as a part of the normal research programme of the Central Building Research Institute.

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