Chapter 3

MATERIALS AND METHODS

3.1 Introduction

The efficiency of grouting is mainly dependent on the properties of the grouting materials and appropriate grouting technique. The success of the grouting is dependent on selection and type of grout materials, type of grouted medium, grout mix design and suitable grouting techniques. The specific mechanical properties that are important in the selection of a grout for a specific job include mechanical permeance, penetrability and strength. The selection of
particular grout is dependent on its geotechnical application along with the other factors (Shah & Shroff 1992).

The technology of grouting has wide range of applications, varying from filling large fissures in rock to alluvial grouting. The aim of the present investigation is to control the properties of grout materials and thereby to improve the bearing capacity and to reduce the permeability of loose sand medium. Wide range of grouting materials are available in the field of grouting, ranging from suspension grouts to solution grouts.

In the present study, suspension grouts have been used. Granular medium was chosen as the formation to be grouted. The details of the grouting materials, grouting medium, grouting procedure and testing methods are presented in the following sections.

### 3.2 Materials

The selection of proper grouting materials depends upon the type of granular medium and the purpose of grouting. Cement, bentonite, clay and lime are the grouting materials normally used for grouting a granular medium. In the present study sand was used as the grouting medium and cement (with or without admixtures), lime and clay were used as the grouting materials.

#### 3.2.1 Sand

As mentioned, sand was used as grouting medium for this study. River sand procured from Kalady, which is a branch of the Periyar river - was dried and sieved into different fractions. River sand of three grades - fine (75 µm-
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425 µm), medium (425 µm- 2 mm) and coarse (2mm- 4.75mm) fractions as per ASTM (D2487-10) and BIS (1498 -1970) classifications were used in the present study. The grain size distribution curves of different fractions of sand are shown in Fig.3.1.

![Grain size distribution curves of sand](image)

**Fig 3.1 Grain size distribution curves of sand**

3.2.2 Cement

43 grade Ordinary Portland cement conforming to IS 269 – 1989 was used for the preparation of cement grouts. The cement bags were kept in air tight bins to avoid any change in the properties with the time of storage. The experiments were planned in such a manner that once a bag of cement was opened, the whole cement was utilized within 10 days. The physical properties
of cement are presented in table 3.1. and its grain size distribution curve is shown in figure 3.2.

<table>
<thead>
<tr>
<th>Sl.No.</th>
<th>Property</th>
<th>Characteristic value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Standard Consistency</td>
<td>28%</td>
</tr>
<tr>
<td>2</td>
<td>Initial setting time</td>
<td>131 minutes</td>
</tr>
<tr>
<td>3</td>
<td>Final setting time</td>
<td>287 minutes</td>
</tr>
<tr>
<td>4</td>
<td>Blaine’s Sp. Surface</td>
<td>298500 mm²/g</td>
</tr>
<tr>
<td>5</td>
<td>Sp. Gravity</td>
<td>3.14</td>
</tr>
<tr>
<td>6</td>
<td>Compressive strength</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(i) 7 days</td>
<td>35.1 N/mm²</td>
</tr>
<tr>
<td></td>
<td>(ii) 28 days</td>
<td>44.0 N/mm²</td>
</tr>
</tbody>
</table>

### 3.2.2.1 Physical properties of cement

The physical properties of the cement used were determined in accordance with IS 269: 1989 and IS 4031: 1988

i) Fineness

The fineness of cement was tested using Blaine’s air permeability test method. This test gives an idea about the fineness of the cement and the specific surface of the cement grains. The test sample of cement was first enclosed in a 125g jar and shaken vigorously for two minutes to fluff the cement and brake up lumps or agglomerations. The weight of the sample was calculated using the expression given in IS: 4031: part 2: 1999. The perforated disc was placed on the ledge in the permeability cell, above which, a filter paper disc was also placed. The cement sample was placed in the cell and the surface was levelled. A filter paper disc was placed above the cement sample and then it was
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compressed with a plunger until the plunger collar was in contact with the top of the cell.

After removing the plunger, the permeability cell was attached to the manometer tube making sure that an air tight connection was obtained, without disturbing the prepared bed of cement. The air in one of the manometer U-tube was slowly evacuated until the liquid reached the top mark and the valve was closed. As the bottom of the meniscus of the manometer liquid reached the second mark, the timer was started and stopped as the meniscus reached the third mark. The time interval was noted in seconds. The specific surface was then calculated using the expression given in IS: 4031: part 2: 1999. As per IS: 269: 1989 the minimum value of specific surface is 2250 cm²/g.

![Fig. 3.2 Grain size distribution curves](image_url)
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ii) Standard Consistency

This test is used for finding out the amount of water required to make a paste of standard consistency. The standard consistency of a cement paste is defined as the consistency which will permit the specific Vicat plunger to penetrate to a point 5 to 7 mm from the bottom of the Vicat mould. 400g of cement was weighed and a paste was made by adding 26% of water, observing that the gauging time is below 5 minutes. The paste was filled in the Vicat mould and the plunger was released. The penetration of the plunger was less than the specified value in IS: 4031: part 4: 1988. The test was repeated by making fresh cement paste with 27 and 28 percentages of water. It was found that when 28 % water was added the penetration of the plunger was within the specified limits.

iii) Initial setting time

The starting of the setting process of a cement paste is based on this property. The working time available with particular cement depends on this. A neat cement paste was prepared with 400 gm of cement and 0.85times the water required for standard consistency. The Vicat mould was filled with this paste and the needle was released. The needle was observed to be piercing completely into the paste. The procedure was repeated until the needle failed to penetrate the cement paste for 5± 0.5mm measured from the bottom of the mould. The period elapsed between the time when water was added to the cement and the time at which the needle failed to penetrate the required amount was reported as the initial setting time.
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iv) Final setting time

This time is used to describe the stiffening of cement paste. The needle for initial setting time was replaced by the annular attachment. The cement paste prepared to determine the initial setting time was placed beneath the attachment in the Vicat apparatus. The attachment was brought down to the surface of the cement paste. Initially, both the central needle and the surrounding attachment made impression on the surface of the paste. Later at 287 minutes, the needle alone made the impression and this was reported as the final setting time.

v) Compressive strength

This is obviously the most required property because it gives an idea about the mechanical strength of hardened cement. The compressive strength is determined by conducting tests on mortar cubes. For making one cube of standard dimensions, 200 gm of cement and 600 gm of specified sand are first mixed well in dry condition and mixed with \( \frac{P}{4} + 3 \) % of water where P is the percentage of water required to produce a paste of standard consistency as described in the earlier section. The prepared mortar was filled in previously cleaned and oiled cube moulds placed on the vibration table. Vibration was given for the specified time and the surface was smoothened with a trowel. The moulds with specimen were kept in a moist room for 24 hours and then detached from the specimens. The mortar cubes were kept in clean water for curing. Compressive strength was determined after 7 and 28 days. Three cubes were tested for each period and the average was reported as the compressive strength.
vi) Soundness

This property is essential that a cement paste, once it has set, does not undergo a large volume change. This test was conducted using a Le-Chatelier apparatus. The cement paste was prepared with 0.78 times the water required to give a paste of standard consistency. The mould was filled with this paste and the assembly was immersed in water for 24 hours. The distance between the indicator points was measured. Submerging the assembly in water, the water was brought to boiling in 25 to 30 minutes and then the distance between these indicator points was measured. The difference between these two measurements represented the expansion of the cement.

vii) Specific gravity

Specific gravity of cement was determined using a Le-Chartelier flask. The flask was filled with kerosene up to the specified portion of the flask and the level was noted. A weighed quantity of cement was poured into the flask carefully taking care to see that the cement did not spill out. The flask was shaken gently so that cement particles did not adhere to the inside of the flask. The final reading was noted. The specific gravity was calculated as the ratio of the weight of cement in grams to the weight of an equal volume of distilled water.

3.2.2.2 Admixtures

Little John (1982) has given a list of admixtures that can be used in cement grouting to improve the various properties of cement based grouts (Table 3.2). Various other authors have recommended a number of additives that can be used in cement as well as bentonite grouting. Admixtures are used in cement grouts to serve as accelerator, retarder, and lubricant or to increase the strength of the grout
Table 3.2. Common Admixtures used along with cement grout

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Admixture</th>
<th>Chemical</th>
<th>Optimum dosage (% by wt of cement)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Accelerator</td>
<td>Calcium chloride</td>
<td>1-2</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>Sodium silicate</td>
<td>0.5-3</td>
</tr>
<tr>
<td>3</td>
<td>Retarder</td>
<td>Tartaric acid</td>
<td>0.1-0.5</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>Triethanolamine</td>
<td>0.1-0.5</td>
</tr>
<tr>
<td>5</td>
<td>Fluidiser</td>
<td>Detergent</td>
<td>0.05</td>
</tr>
<tr>
<td>6</td>
<td>Expander</td>
<td>Aluminium powder</td>
<td>0.005-0.02</td>
</tr>
<tr>
<td>7</td>
<td>Antibleeder</td>
<td>Bentonite</td>
<td>2-10</td>
</tr>
<tr>
<td>8</td>
<td></td>
<td>Aluminium sulphate</td>
<td>Up to 20%</td>
</tr>
</tbody>
</table>

Among the accelerators, calcium chloride and sodium silicate were used in the present investigation. To study the effect of retarders, triethanolamine and tartaric acid were chosen. The fluidiser used was detergent, which is commercially available soap powder (sun light detergent powder was used here). Aluminium powder was used as the expander. Aluminium sulphate and bentonite were used as antibleeders.

3.2.3 Bentonite

The bentonite used in this study is a commercially available, highly expansive one. The properties of the bentonite are given in table 3.3. Bentonite shows great affinity towards moisture. The percentage of water present in a sample of bentonite varies depending upon the climatic condition. So the bentonite, which was thoroughly mixed uniformly, was preserved in double layer of polythene bags. Again these bags were stored in airtight bins.
Table 3.3 Properties of bentonite

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Property</th>
<th>Characteristic value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Specific gravity</td>
<td>2.8</td>
</tr>
<tr>
<td>2</td>
<td>Liquid limit (%)</td>
<td>410</td>
</tr>
<tr>
<td>3</td>
<td>Plastic limit (%)</td>
<td>45</td>
</tr>
<tr>
<td>4</td>
<td>Plasticity index (%)</td>
<td>365</td>
</tr>
<tr>
<td>5</td>
<td>Shrinkage limit (%)</td>
<td>1.34</td>
</tr>
<tr>
<td>6</td>
<td>Volume change (%)</td>
<td>97.5</td>
</tr>
<tr>
<td>7</td>
<td>Linear shrinkage (%)</td>
<td>49.61</td>
</tr>
<tr>
<td>8</td>
<td>Activity</td>
<td>5.03</td>
</tr>
<tr>
<td>9</td>
<td>Free swell index (cc/g)</td>
<td>17.5</td>
</tr>
<tr>
<td>10</td>
<td>Cation exchange capacity (meq/100g)</td>
<td>60.8</td>
</tr>
<tr>
<td>11</td>
<td>pH</td>
<td>7.4</td>
</tr>
<tr>
<td>12</td>
<td>Surface area (m²/g)</td>
<td>87.5</td>
</tr>
<tr>
<td>13</td>
<td>Conductivity (µS/cm²)</td>
<td>10800</td>
</tr>
<tr>
<td>14</td>
<td>Organic matter (%)</td>
<td>1.48</td>
</tr>
</tbody>
</table>

Physical properties of Bentonite

i) Atterberg limits

The liquid limit and plastic limit were determined as per IS 2720: part 5: 1985. The liquid limit test was conducted using Casagrande apparatus, starting from a water content which required only around 10 blows for the groove to close. The paste was then allowed to spread over a glass plate to allow evaporation. This was then mixed thoroughly for the next test. The liquid limit was reported as the water content which took 25 blows to close the groove.
Plastic limit was found out as the water content required just to make hair line cracks for the clay thread of specific diameter of 3 mm.

ii) Grain size distribution

Grain size distribution of the grout suspension is a very important property in grouting practice. The sedimentation analysis was done using a hydrometer. Grain size distribution curve is shown in figure 3.2

3.2.4 Cochin marine clay

Marine clay was collected from a site at Elamkulam in Greater Cochin area on the Western coast of India. Bulk samples of the clay were collected from bore holes advanced by shell and auger method.

The boring operations were taken to the clay layers for collection of samples. The boring operations were carried out as per IS: 1892: 1979, Code of practice for subsurface investigations for foundations. Care was taken not to include bentonite slurry during the boring operations as it could contaminate the soil samples. Samples collected from different locations were put together and mixed thoroughly into a uniform mass and preserved in polythene bags. The grain size distribution curve of the marine clay is shown in figure 3.2

3.2.5 Lime

Specially selected uniform shells were used for preparation of lime for the study. The shells were burnt to remove CO₂ completely when they change to brittle white shells of calcium oxide which were preserved in airtight
multilayer polythene bags. The required amount of water alone was sprinkled over the loose shells taken from these bags on each day of lime treated samples, till all the shells crumble to fine powder which was then sieved through IS 425 micron sieve. This method of preparation of lime was used because of its simplicity and the ease with which it can be prepared for field application.

3.3 Grouting operations

To place the grout within the pores of the granular medium, two procedures were adopted. In the first method, the grout material was deposited within the pores by hand mixing. In the second method, previously prepared sand beds were grouted with different grouting materials by using a grout pump to simulate the grouting operations in the field. The preparations of both these types are described in detail below.

3.3.1 Grout impregnation by hand mixing

The grouting materials like cement, lime, etc. with or without admixtures were hand mixed uniformly with the sand for the preparation of test specimens.

(i) Grouting with cement

A unit weight of 14.5 kN/m$^3$ for sand was chosen for the preparation of samples, so that the relative density is 51%. This was selected by considering the fact that it can be achieved relatively easily with very good reproducibility and by considering the difficulty experienced in preparing the samples at unit weights corresponding to the loosest state. The required amount of sand of
specific size range was taken in a tray. The predetermined quantity of cement (2, 4, 6, 8, 10, 15, 20 & 25% by weight of sand) was then added to the sand and thoroughly mixed with a trowel. Water was (5, 10, 15, 20 or 25% by weight of sand and cement) sprinkled over the cement sand mixture and thoroughly mixed with a trowel. This was filled in split moulds of size 60 mm x 60 mm x 25 mm in two layers to obtain specimens for direct shear tests and also filled in cube moulds of size 70.6 mm x 70.6 mm x 70.6 mm, to obtain specimens for compressive strength tests. These specimens were kept at room temperature for 24 hrs, then taken out from the moulds and kept for curing for periods of 7 and 28 days. Specimens prepared for direct shear tests like this are shown in Fig 3.3 (ii) Grouting with cement and admixtures

To the cement-sand mixture prepared as explained earlier, predetermined amount of admixture (% by weight of cement) dissolved in water (10% by weight of sand and cement put together) was added. This ensured uniform mixing of all the materials. This was then filled in split moulds of size 60 x 60 x 25 mm, in layers to obtain samples for direct shear tests and in cube moulds of size 70.6 mm to obtain samples for compressive strength tests. These specimens were cured before testing, as explained.
3.3.2 Grout impregnation by pumping

Predetermined quantity of cement with or without admixtures was taken and thoroughly mixed with a definite amount of water. The slurry was thoroughly mixed for 10 minutes at 3000 rpm using a standard stirrer. The grouting setup consists of a grout chamber with agitator, air compressor, grouting nozzle and regulating valve. The grouting nozzle was kept in position (at 5 cm above bottom level of tank) and the sand bed was prepared in a tank of size 45 cm x 45 cm x 60 cm / 1 m x 1 m x 0.60 m at the loosest state (unit weight of 13.1 kN/m$^3$ and an initial void ratio of 0.98). Sand was filled in the tank by pouring through a funnel from a constant height of 1m from the top of the sand bed. Then the slurry (grout) was poured into the grout chamber. In order to reduce the possibility of settling of the grout in the grout chamber, an agitator was provided inside the grout chamber. Grout was pumped under a constant pressure of 5 kg/cm$^2$ (500 kPa) into the prepared sand bed. The grouting nozzle was raised during the grouting operation at regular intervals in
order to get uniform flow of grout over the entire thickness of the sand bed. The grouted sample was kept for curing under moist condition.

3.4 Testing methods

In this investigation shear strength, compressive strength and permeability of cement grouted sand were studied in detail. The physical properties of grouting materials were also tested. The various test procedures are discussed in detail as follows.

3.4.1 Shear strength test

The shear strength can be determined in the laboratory by direct shear box test or triaxial test. In the present study, direct shear tests were conducted for the determination of the shear strength parameters. Saturated specimens (of size 60 mm x 60 mm x 25 mm) prepared as per the procedure given in section 3.3.1 were placed in the split mould. Perforated metal plates were placed above and below the specimen to allow free drainage. A pressure pad was placed on top and the entire box was placed in the trolley. A vertical load was applied to the specimen through a static weight hanger and the specimen was sheared by applying a horizontal force which causes the two halves of the box to move relative to each other. The shear was applied at a constant rate of strain of 0.25mm/ min. The magnitude of shear load was measured by means of a proving ring. The shear deformation as well as the vertical deformation was measured during the test with the help of dial gauges. The procedure was repeated on four specimens, each subjected to different normal loads. Normal stress and the shear stress on the failure plane were obtained by dividing the normal force and shear force by the nominal area of the specimen. Values of shear stress at failure were plotted against the normal stress for each test. The shear strength parameters $c$ and $\phi$ were obtained from the best fit straight line through those points.
3.4.2 Compressive strength test

The compressive strength of grouted specimens was determined by conducting tests on 70.6 mm cube specimens. Hand impregnated specimens were prepared in the mortar cube moulds and grouted specimens were cut into this size from the grouted mass by a diamond concrete cutter. The specimens were placed in the loading frame in the proper position and axial load was applied at a constant strain rate of 0.02mm/min. The magnitude of load and deformations were measured with the help of a proving ring and dial gauges. The compressive stress was obtained by dividing axial force by the cross sectional area of specimen. Three identical specimens were tested and the average value was taken as the compressive strength.

3.4.3 Cross sectional area of grouted mass

A preliminary idea about the grouting efficiency can be obtained from the cross section area of the actual grouted medium at different depths. For this purpose, once the grouting was over and sufficient time allowed for curing, the side walls of the tank were removed so that the dimensions of various cross sections of the intact grouted mass at different depths could be taken. Lateral measurements were taken from the centre of the grout hole to the corners and centers of the side walls and additional measurements were also taken in case of uneven shapes. For this purpose, a cage made of steel bars with the same lateral dimensions as that of the tank was fabricated. Keeping this cage encompassing the grouted mass facilitated easy measurements of the dimensions. All the measurements were taken at 10 cm intervals from the top of the grouted bed and recorded. With the help of these measurements cross sections were drawn and the area was calculated at different intervals.
Fig. 3.4 (a) Collection of test specimens from grouted samples in progress

Fig. 3.4 (b) Collection of test specimens from grouted samples in progress
3.4.4 Cement content determination

The efficiency of grouting and lateral flow of grouts were also analyzed by determining the cement content at various places of the grouted mass. For this purpose, samples were collected at different distances radially from the centre of the grout hole at different depths. The process of collecting the samples by cutting the grouted mass with the help of a diamond cutter is shown in Figs 3.4 (a) and 3.4 (b). Samples at the same radial distance (at a particular depth) were mixed together and were used for the purpose of cement content determination. The procedure adopted for the determination of cement content is given below.

This test method covers the determination of cement content by chemical analysis of hardened soil-cement mixtures. ASTM standards designation D806-00; Standard test method for cement content of hardened soil- cement mixtures were used in this test. A similar method was also presented in BIS (IS:4332 - 1973) “Method of test for stabilized soils part VII method of determination of cement content of cement stabilized soils”. This test method determines the cement content in mixtures of cement with soil by chemical analysis. It was developed primarily for testing samples for which a significant degree of cement hydration or hardening has taken place.

The method involves the determination of the CaO contents in the soil (sand), cement and in the grouted mass, separately. The procedure for conducting the chemical analysis is explained below.

Take 25 g of each of the above samples after drying in an oven at 110 ± 5°C to remove free water. Sieve the samples through a 425 μm sieve. Each sample is prepared in the following amounts: raw soil, 5 g; soil-cement mixture, 5 g; and cement, 1 g. Each sample is placed in a 250-ml beaker and 50 ml of
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HCl (1 + 1) is added to each sample, then covered, and boiled gently for 5 min on the hot plate. Add 25 ml of hot water to this, stir well and allow to settle momentarily, and then decant the contents through a Whatman No. 1 filter paper. The filtrate should be received in a 250-ml volumetric flask. When the liquid has passed through the filter paper, wash the residue once by decantation, using hot water, then transfer it to the filter, using a stream of hot water. The beaker should be rapidly policed, the loosened material being transferred to the filter paper. The material on the filter should then be washed four times more, each washing consisting of 10 to 15 ml of hot water directed in a stream from the wash bottle. Very small amounts of residue would occasionally pass through the filter, which may be disregarded.

When washing is completed, discard the filter, and dilute the filtrate in the volumetric flask to 250 ml with cold water. Agitate the flask to mix the contents thoroughly, then remove a 50-ml aliquot and transfer it to the original 250ml beaker, using a 50ml pipette and dilute it to 100 ml. Make the solution slightly ammoniacal, boil it for 1 to 2 min, and allow the hydroxides to settle. Filter the hydroxides through an 11-cm Whatman No. 1 filter paper, receiving the filtrate in the 600-ml beaker. Wash the original 250-ml beaker into the filter once with a stream of hot NH₄NO₃ solution (20 g/l), and follow by washing the hydroxide precipitate once or twice with hot NH₄NO₃ solution. Set this aside, and place the original beaker under the funnel. Perforate the paper with a rod, and wash the hydroxides down into the original beaker, using a stream of hot NH₄NO₃ solution (20 g/l) to remove most of the precipitate from the filter paper. Treat the paper with 20 ml of hot HCl (1 + 3), directing the acid over the paper with a glass rod. Wash the paper several times with hot water, and then discard the paper and dilute the solution to 75 ml. Fig. 3. 5 shows the test set up for cement content determination.
Make the solution slightly ammoniacal and boil it for 1 to 2 min, allow the precipitate to settle, then decant through a Whatman No. 1 paper as before, receiving the filtrate in the 600-ml beaker previously set aside. Wash and police the beaker in which precipitation take place, finally washing the precipitate on the filter three or four times with NH₄NO₃Solution (20 g/l). Discard the hydroxide precipitate. Add 2 ml of NH₄OH (sp gr 0.90) to the filtrate, which will now have a volume of 250 to 350 ml. Heat the solution to boiling and add 10 ml of hot saturated ammonium oxalate solution. Keep the mixture near boiling until the precipitate becomes granular; then set it aside on a warm hot plate for 30 min or more. Before filtering off the calcium oxalate, verify completeness of precipitation, and make sure that a slight excess of NH₄OH is present. Filter the mixture through an 11-cm or 15-cm Whatman No. 2 filter paper, or if preferred a Whatman No. 42 paper, making sure that all the
precipitate is being retained. Thoroughly clean with a rubber policeman, the beaker in which precipitation took place and transfer the contents to the filter with a stream of hot water. Wash the filter eight to ten times with hot water (not more than 75 ml), using a stream from the wash bottle.

Carefully open the filter paper and wash the precipitate into the beaker in which the precipitation was effected. Dilute it to 200 ml and add 10 ml of $\text{H}_2\text{SO}_4(1 + 1)$. Heat the solution just short of boiling, and titrate with the standard $\text{KMnO}_4$ solution to get a persistent pink colour. Add the filter paper and macerate it. Continue the titration slowly until the pink color persists for 10 s.

Make a blank determination, following the same procedure and using the same amount of all the reagents.

**Calculation**

The cement content of the grouted sample is computed as follows

The percentages of CaO in the soil, in the cement, and in the grouted samples can be calculated as:

$$\text{CaO,} \% = \frac{0.028(A - B)C}{D} \times 100$$

Where:

$A = \text{KMnO}_4$ solution required for titration of the sample in ml,

$B = \text{KMnO}_4$ solution required for titration of the blank in ml,

$C = \text{normality of the KMnO}_4$ solution,

$D = \text{sample represented by the aliquot titrated in gms}$ and

$0.028 = \text{CaO equivalent of 1 ml of 1.0 N KMnO}_4$ solution.
Percentage of cement by mass of soil can be determined as

\[
\text{Cement, } \% = \left( \frac{G - F}{E - F} \right) \times 100
\]

\[
E = \text{CaO in the cement (\%)}
\]

\[
F = \text{CaO in the soil (\%)} \text{ and}
\]

\[
G = \text{CaO in the grouted sample (\%).}
\]

### 3.4.5 Load tests

The efficiency of the grouting process was also verified through load tests conducted on ungrouted/grouted sand beds. The initial tests for the assessment of improvement in load carrying capacity through densification, were conducted by filling the sand at the desired densities in small tanks of size 30cmx30cmx30cm. For estimating the load carrying capacity of grouted beds, the grouting operations were done in large tanks of size 1mx1mx0.6m. Uniform sand beds in the loosest state (unit weight 13.1 kN/m³) were prepared after keeping the detachable side walls of the tank in position. Grouting was done as per the procedure given in section 3.3.2. The disturbed portion at the top for a depth of 10cm was removed, and after curing for a period of 28days, load test was conducted in this grouted bed. The load was applied through a 20cm square plate with the help of a hydraulic jack. Dial gauges mounted on the opposite corners of the plate gave the settlement corresponding to the load (read from the pressure gauge).

### 3.4.6 Permeability

Permeability is defined as the property of a porous material which permits the passage or seepage of water or other fluids through its interconnecting voids. Gravel is highly permeable while stiff clay or high
plastic clay is least permeable. The flow of water through soils may be laminar or turbulent. In most of the practical flow problems in geotechnical engineering, the flow is laminar. The flow of water through soil obeys Darcy’s law which states that the rate of flow is proportional to the hydraulic gradient. The coefficient of permeability can be determined in the laboratory by constant head test or falling head test. In the present study, constant head tests were conducted for the determination of the permeability. Rigid wall permeameters (standard concrete permeability test apparatus) of size 150 mm x 150 mm x 150 mm were used. The sand was filled in the mould keeping the dry unit weight of sand as 14.5 kN/m³. Water was permitted through the sand medium under a constant head of 2m (20 kPa). The discharge was measured once a steady state condition is reached. The test setup is shown in figure 3.6.
For preparing the hand impregnated cement/bentonite grouted samples, medium sand (unit weight 14.5 kN/m$^3$) was mixed with predetermined percentages of cement/bentonite (2, 4, 6, 8 & 10 % by weight of sand) in the dry condition. Then 10% of water (by weight of sand + cement mixture) was added to this, thoroughly mixed and filled in the mould in layers to achieve a uniform mass. These permeability specimens were allowed to cure under saturated condition by permitting the flow at a very small head.

Discharge measurements were taken at a constant head of 2m at different curing periods (in the case of a few specimens) in order to check whether the permeability is affected by the curing period of the grouted specimens. From a series of experiments, it was found that the permeability goes on reducing upto a curing period of around 15 days. Hence permeability tests on subsequent samples were done after the specimen has undergone a curing for 15 days.

To study the effect of grouting with locally available clay on the permeability of the sand medium, Cochin marine clay in moist condition (at natural water content) was mixed with sand before filling in the permeability moulds. Similarly for preparing specimens to study the effect of additives such as cement/lime, the predetermined percentage of cement/lime in powder form was mixed with Cochin Marine clay (in moist condition) and then mixed with sand before filling in the permeability moulds. For all these tests, care was taken to keep the unit weight of sand in the mould as 14.5 kN/m$^3$. 