Permeability of A Composite Seawall: Effect of the Orientation of Gaps in the Structure

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Abstract. A Seawall requires reflecting and dissipating entire wave energy with zero transmission. The permeability would significantly affect its hydraulic stability under wave loads. Thus, the permeability of a structure changes with the material and consequently a variation in the composite structure may give a different perspective on the hydraulic performance of a seawall altogether. As a first step towards establishing the composite seawall, a comprehensive permeability test is performed as a preliminary assessment of hydraulic conductivity. In the current research, a bag made of non-woven geotextile polymer filled with sand and a roll of non-woven needle punched coir geotextile is investigated. A total number of 20 model tests were performed by varying the orientation and positions of the material composites and thereby the gaps in the structure. The results are noted and future research possibilities into the design and development of a composite seawall as an alternative to traditional seawall are thus presented.

1. Introduction
Around half of the population of the world resides within 100 km of the coastal region [1]. Protection of coastal areas from the erosion caused especially due to the invasion of the natural process by the construction of infrastructure like harbours, need special attention. Geosynthetics are gaining popularity around the globe for coastal erosion control applications over the traditional rubble mound structures due to ease of operation and installation. The types of geosynthetics used for coastal protection are geosynthetic sandbags/containers (GSC), geotubes, geocells, etc. There is ample
research going on in the variety of geosynthetic that is used in coastal applications, naming a few: geocells, geocomposites, etc. [2]–[5].

Globally, the use of geosynthetics in the construction of a seawall is in the form of geosynthetic sandbags[6]. It is considered as a soft technic, as an alternative protecting mechanism against rubble mound or concrete seawalls. There is a huge scope for research on the performance of geosynthetics under varying environmental conditions. Vandalism is one of the critical problems, prevention of which may primarily require submerged structures to be constructed. Laying such mechanisms requires heavy machinery which may not be readily available [7]. Hence, coast specific as well as cost-effective protection techniques could be a viable alternative for research. Secondly, covering the structures with sand remains an option for consideration.

This calls for research into composite material combinations for the design of a seawall. The primary purpose of a seawall is to reflect and dissipate the wave energy. No transmission can be allowed for such a structure. The dissipation of wave energy is a function of interstitial spaces and porosity of the structure armour layers. Thus, there is a need to assess the porosity and permeability of the composite structure, which can give directions in conducting a further physical investigation on the energy dissipation performance of the composite structure.

This paper focuses on a novice combination of geosynthetic sand containers with organic product coir geosynthetic, which is available in abundance in the coastal regions. Thus deeming to large scale availability of material, this can be used for temporary erosion control projects. The test was carried out as a preliminary assessment to find the permeability of the composite structure, involving the influence of the size of the bag and coir, the gaps between the materials, and the existence of two different elements in the construction of a seawall.

2. Materials and methods

The hydraulic permeability test was performed in the wave flume of Symbiosis Institute of Technology (SIT) with dimensions size 10m x 0.5m x 1m. (figure 1)

![Figure 1. Schematic sketch of tilting flume of SIT](image)

Two motors of 0.5 horsepower supply the water in the tilting flume. The flume is equipped with a discharge indicator at the bottom and three control valves at the inlet. There is also a reverse discharge collection pipeline at the bottom of the flume which can further accelerate the discharge collection at the time required. It has two acrylic gates provided at either end of the flume with 6.9 m distance apart from each other to convert the tilting flume to a wave tank. A mechanical flap-type wavemaker is installed at one end of the flume for the generation of regular waves. A velocimeter of is used for measuring the wave velocity on downstream of the structure.

The material used for the present study is a non-woven needle-punched geotextile table 1 procured from Maccaferri Environmental Solutions Pvt. Ltd. [8-10]. The encapsulated sand is procured from the local market. The geotechnical properties are, as mentioned in table 2. Figure 1 shows the grain size analysis of sand.
Table 1. Specifications of the non-woven needle-punched geotextile.

| Property                      | Units       |
|-------------------------------|-------------|
| Grab Tensile Strength         | 1110N       |
| Grab                          |             |
| Elongation                    | > 50%       |
| CBR Puncture Strength         | 3110N       |
| Trapezoidal Tear Strength     | 450N        |
| UV Resistance                 |             |
| AOS                           | less than 75 micron |
| Water flow                    | 50 l/sqm/sec|

Table 2. Geotechnical properties of sand.

| Property          | Value | Units |
|-------------------|-------|-------|
| Specific gravity  | 2.68  | -     |
| Relative Density  | 69.8  | %     |
| Permeability      | 1.34x10^{-6} | cm/sec |
| Cu                | 5.12  | -     |
| Cc                | 1.09  | -     |

Figure 2. Particle size distribution diagram

The coefficient of Uniformity (Cu) is a measure of the particle size range. It can be calculated by taking a ratio of $D_{60}$ to $D_{10}$. For a uniformly graded soil, Cu =1. For a well-graded soil, Cu > 4 for gravel, Cu > 6 for sand. Based on the range of the coefficients the characteristics of the soil are decided, whether it is well-graded, poor or uniform. Therefore the soil used in the present investigation falls in the range of sandy gravel based on the Cu value. The coefficient of curvature (Cc) is the shape of the particle size curve. It can be determined as a ratio of the square of $D_{30}$ to the product of $D_{10}$ and $D_{60}$.
For a well-graded soil, $C_c = 1$ to $3$. The size of the sandbag was 0.5m x 0.2m x 0.1m figure 3. The size was selected such that the width of the entire flume is occupied and depth shall be aiding to the ease of handling. The needle-punched coir geotextile was cut in the size of 1m x 0.5m and rolled such that the diameter of 10 cm is obtained. The sandbag was filled 80% by volume with sand [11].

3. Experimental program
To assess the effect of mode of placement of the composite material on the overall permeability of the seawall, A total of 20 model tests were performed in the test program. Variations were made in the placement and positioning of the coir and sandbag. This resulted in the variation of the number and size of gaps in the composite structure.

![Figure 3. Schematic model configurations for the comprehensive tests of permeability.](image)

To calculate permeability, the reading of the head (h1) at the upstream of the flume was maintained constant, whereas the head (h2) at the downstream was measured manually. The head difference (H) on the upstream and downstream was noted. The length (L) of the structure which is the inclined distance from upstream to downstream was measured, using which the hydraulic gradient (i) was calculated. The discharge was calculated after recording the time required for acquiring a set volume (0.0162 m$^3$/sec) of water and noting the head difference for that particular loss of time. Hence, using Darcy’s Law, the permeability $k$ was then computed Table 4 employing in Area $A$, Hydraulic gradient $i$, and the discharge $Q$. Each test was carried out four times and the average value of $k$ was noted. The permeability coefficient of the non-woven geotextile polymer bag used in the test $k = 0.5$ cm/sec, of the non-woven coir $k = 11860$ lit/m$^3$/min, and the sand of grain size of $D_{90} = 2.36$ mm $k = 1.34 \times 10^{-6}$ cm/sec.
Table 3. Schematic model configurations for the comprehensive tests of permeability.

| MODEL NAME | CROSS SECTION | SIDE VIEW | TOP VIEW | MODEL NAME | CROSS SECTION | SIDE VIEW | TOP VIEW |
|------------|---------------|-----------|----------|------------|---------------|-----------|----------|
| M1         | GAP           |           |          | M11        | GAP           |           |          |
| M2         | GAP           |           |          | M12        | GAP           |           |          |
| M3         | GAP           |           |          | M13        | GAP           |           |          |
| M4         | GAP           |           |          | M14        | GAP           |           |          |
| M5         | GAP           |           |          | M15        | GAP           |           |          |
| M6         | GAP           |           |          | M16        | GAP           |           |          |
| M7         | GAP           |           |          | M17        | GAP           |           |          |
| M8         | GAP           |           |          | M18        | GAP           |           |          |
| M9         | GAP           |           |          | M19        |               |           |          |
| M10        | GAP           |           |          | M20        |               |           |          |

4. Results and discussion

In the model arrangements where coir was the first layer of the structure, the water seemed to flow faster; however if sand was the first layer the permeability is relatively slower. This is due to the difference in voids ratio, and thereby the porosity of the GSB and Coir roll. The average permeability for each model is as shown in figure 4. The range of permeability lies between 0.02 m/sec to 0.2 m/sec. The highest value of the coefficient of permeability is obtained for M20 configuration. In this arrangement, the geobags and coir rolls were arranged by dropping them randomly, thus creating larger sized gaps. The next highest permeability is obtained in M12 as 0.135 m/sec. In this arrangement, the coir rolls were aligned along the side of the flume, resulting in faster gush out of water. The least permeability is observed for variation M1 which is 0.02 m/sec followed by M2, as the water passed only via the small side gaps around the GSC bag and coir. The water was first absorbed by the coir interstices and then passed through.
Table 4. Permeability values for each configuration type.

| Model No. | Q($10^{-3}$m$^3$/s) | L (m) | H (m) | i    | A (m$^2$) | k (m/s) |
|-----------|----------------------|-------|-------|------|-----------|--------|
| M1        | 3.0567               | 0.5   | 0.36  | 0.72 | 0.192     | 0.0221116 |
| M2        | 7.1366               | 0.6   | 0.33  | 0.55 | 0.192     | 0.0675815 |
| M3        | 5.0311               | 0.77  | 0.342 | 0.444156 | 0.192 | 0.0589966 |
| M4        | 3.9037               | 0.79  | 0.35  | 0.443038 | 0.192 | 0.0458918 |
| M5        | 3.7328               | 0.89  | 0.34  | 0.382022 | 0.192 | 0.0508915 |
| M6        | 3.4469               | 0.82  | 0.348 | 0.42439 | 0.192 | 0.0423022 |
| M7        | 3.6                  | 0.72  | 0.35  | 0.486111 | 0.192 | 0.0385715 |
| M8        | 2.8422               | 0.8   | 0.365 | 0.45625 | 0.192 | 0.0324453 |
| M9        | 3.9513               | 0.7   | 0.365 | 0.521429 | 0.192 | 0.0394679 |
| M10       | 9                    | 0.67  | 0.347 | 0.5191 | 0.192 | 0.090508 |
| M11       | 3.7675               | 0.79  | 0.362 | 0.458228 | 0.192 | 0.0428224 |
| M12       | 6.2308               | 0.83  | 0.345 | 0.415663 | 0.192 | 0.0780732 |
| M13       | 3.7675               | 0.76  | 0.356 | 0.468421 | 0.192 | 0.0418906 |
| M14       | 3.0567               | 0.78  | 0.362 | 0.464103 | 0.192 | 0.0343035 |
| M15       | 3.8572               | 0.85  | 0.365 | 0.429412 | 0.192 | 0.046784 |
| M16       | 3.4469               | 1     | 0.36  | 0.36  | 0.192 | 0.0498684 |
| M17       | 3.0567               | 0.85  | 0.366 | 0.430588 | 0.192 | 0.0369735 |
| M18       | 2.418                | 0.86  | 0.37  | 0.430233 | 0.192 | 0.029272 |
| M19       | 2.418                | 0.97  | 0.368 | 0.379381 | 0.192 | 0.0331955 |
| M20       | 6.75                 | 1.06  | 0.355 | 0.334906 | 0.192 | 0.1049736 |
The portions where the sandbags and coir meet each other create a gap, which allows the water to pass through, without which the permeability through the geotextile sand-filled bag is otherwise minimal. The gaps in models such as M1 where the gaps are overlapped with longitudinal sandbags, the permeability was lesser than the models wherein the arrangement of the structure is perpendicular to the flow. The presence of coir along with the GSC bag in the composite seawall in any alternative layout impacts the time of the discharge, in turn, the permeability.

5. Conclusion
Permeability is inversely proportional to the cross-section area of the structure through which water is required to flow, length of the medium, and directly proportional to the head of water. This is particularly applicable for a single material with the uniform property. For material with two or more composites, the geotechnical properties of the complete structure would affect the overall permeability of the structure. Also, the field permeability values of such a structure would be different. In this study, an attempt is made to assess the effect of positioning of the material composites to the permeability in-situ conditions. It is observed that the arrangement affects the size and number of gaps, which thereby affects the overall permeability through the structure. The material undertaken for this study consists of coir, which is a material of interwoven coconut fiber threads and soil which is a particulate material. The combination of these material types leads to faster seeping of water into the coir roll and relatively slower saturation of geosynthetic sandbags wherein the water has to seep through all voids before finding the way out on the other side. The difference in individual permeability and the combination can, therefore, be utilized such that the wave energy gets dissipated in the act of flowing through the voids in a fast and slow pace. The results indicated that the arrangement of the structure can significantly alter the overall permeability characteristics of the seawall and therefore the energy dissipation capability of the same. Further work is possible to assess more materials with varying permeability and form a relationship of permeability of a matrix to the energy dissipation. This would lead to research on the possibilities of utilization of composite materials in the construction of a seawall.
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