THE EXPERIMENTAL STUDY OF SOIL CEMENT BULKHEAD MODEL TO REDUCE SALTWATER AT COASTAL AQUIFER

Nurnawaty
Doctoral Student of Civil Engineering Department,
Hasanuddin University, Makassar,

Mary Selintung
Professor, Civil Engineering Department,
Hasanuddin University, Makassar

Muhammad Arsyad Thaha
Associate Professor, Civil Engineering Department,
Hasanuddin University, Makassar

Farouk Maricar
Associate Professor, Civil Engineering Department,
Hasanuddin University, Makassar

ABSTRACT

Artificial barrier on sub surface ground is one of seawater intrusion control methods physically in the coastal area. This study aims to assess the effect of soil cement insulation as a barrier subsurface intrusion against saltwater intrusion into freshwater at Coastal unconfined aquifer. The research was conducted by testing experimental models in laboratory with 4 variation of insulation’s depth (D) and 3 variation insulation width (B). This study uses coastal sand as the basic material for making the aquifer model with 0,031 cm/s. Water used is freshwater with specific gravity 1,000 gram/cm³ and saltwater with specific gravity 1,025 gram/cm³ and insulation barrier by mixture cement-water 1 : 6. The results indicate that artificial barrier subsurface by soil semen insulation can reduce the length of saltwater intrusion. With increasing value insulation dimension (depth and width), While at D = 2 cm the length of intrusion reduce 8,08%. D = 5 cm length of intrusion reduce 18,70 % and D = 10 cm length of intrusion reduce 46,24 %.

Keywords: Saltwater Intrusion, Physical Barrier, Soil-Cement Insulation, Coastal Aquifer
1. INTRODUCTION

The soil or rock of constituent at the coastal area generally in the form of sand or coral will cause seawater easily enter into freshwater, this flow occurs because of seepage through the pores, seepage value on the beach sand can be reduced by changing the pore size so the water volume passes through will be reduced by making the artificial material of soil and cement mixture that is inserted into the soil or sand (soil cement) Thus forming a new soil structure with different permeability values [1], the influence of cement mixture in the manufacture of cemented soil [8]

Research conducted by [2] to stop sea water intrusion in coastal aquifers at Salento, Italy created a barrier design using Gypsum, (Hendrik, 2009) [10] a seawater intrusion model on a phreatic aquifer, (Jun Shou, 2009) [13] investigated permeability changes using long = 25 cm column of beach aquifer sediments at China, [5&17] developed a permeation grouting method of pole on the sand soil carried out in the foundation of diameter pole = 10 cm and length = 170 cm. Resulting in better grouting quilts than other mixtures that can increase the average tensile capacity on a 562% grouting pole foundation. [23] about grouting; Estimate the amount of injection fluid required, and determine the amount of water passage in the soil and the magnitude of the permeability coefficient.

Subsurface barrier design based an environmentally besides inhibit saltwater seepage also serves as a reinforcement of subsoil on coastal buildings that can serve to protect freshwater reserves. This is necessary as one of the preventive measures to prevent pollution of soil moisture due to excessive saltwater intrusion which can lead to changes in salinity and clean water crisis. One way that can be used to minimize saltwater seepage is to create a physical barrier subsurface made of a mixture of cement and soil to decrease the seepage velocity value. It is planned to conduct laboratory-scale research to find out; materials and dimensions of bulkhead (depth and thickness) to reduce saltwater seepage into freshwater soil in the soil layer inside.

The relationship between seawater and freshwater underground on a coastal aquifer in a static state can be explained by Ghynben-Herzberg's law [11]. [12] Given the differences in density between seawater and freshwater underground, the interface is dependent on the balance of the two, the relationship between brine and freshwater underground at free aquifers in coastal areas as shown in Figure 1

![Figure 1 The relationship of saltwater and freshwater at unconfined aquifers in coastal areas [24]](image_url)
Equations of saltwater and freshwater balance in coastal areas are:

\[ h_s = 40 h_f \]  

Dimana:
- \( \rho_s \) = density of seawater = 1,025 gr/cm\(^3\)
- \( \rho_f \) = density of freshwater = 1,000 gr/cm\(^3\)
- \( h_s \) = the depth of saltwater
- \( h_f \) = The depth of freshwater from surface seawater level

This study aims to determine the characteristics and ability of coastal sand to water flow, to determine the level of soil permeability by making soil cement mixture in reducing the rate of seawater intrusion in laboratory scale. This research makes a model of soil cement bulkhead as a subsurface barrier into soil / sand beach that can react with the level of salinity by considering the thickness or depth of the bulkhead which is intended to reveal the condition of flow interpretation.

2. THEORETICAL REVIEW

2.1. Soil Cement

Soil-cement is a mixture of soil (loose) and a certain amount of Portland Cement and water compacted to maximum density, then hardened with cement hydration [14] & [15]. The cement used is Portland cement according to the requirements of ASTM, ASSHTO, CSA or other specifications of cement type I and IA, the normal and waterproof type, most commonly used, (PCA-1969 Essential of Soil-cement) At soil-cement maximum density conditions can be achieved. Additive is required only to improve the performance of conventional soil-cement to reduce cracking due to cement hydration and to help increase the binding of cement through the electrochemical process by neutralizing the activating ions to obtain greater compression on strength of the material [16].

2.2. Groundwater Flow

The general equation of groundwater flow in the unconfined aquifer is as follows[20]:

\[ \frac{k}{2} \frac{\partial^2 h}{\partial x^2} + \frac{k}{2} \frac{\partial^2 h}{\partial y^2} + k \frac{\partial h}{h} = n \frac{\partial h}{\partial t} \]  

Groundwater flow through long aquifer without variation then the aquifer's storage capacity is always full and steady flow, so that the flow is only to the x-axis and the axis \( Y = 0 \) and no additional flow (recharge), then the magnitude of the discharge on this aquifer is:

\[ Q = wK \frac{h_s^2 - h_0^2}{2l} \]  

2.3. Seawater Intrusion

Seawater intrusion is the process of entering saltwater from the sea into freshwater passes by the water/river or soil of the land subsurface of the aquifer in the coastal area. Saltwater can mix with surface water in the delta and beach areas: salt supply through the atmosphere, salt entry through the voyage, intrusion of seawater into the estuary, brackish groundwater seepage into low areas, salt diffusion on salted soil, drainage saline Effluent and salt content in river water. The length of seawater seepage in coastal aquifers depends on: aquifer thickness or water-saturated zone thickness, Coefficient of permeability (value \( K \)) and discharge of groundwater per unit of aquifer area. [18]. Physical attempts to reduce the
seawater intrusion into the aquifer include: reducing groundwater pumping discharge, freshwater injection, saltwater extraction, and subsurface barrier [19], groundwater fillings through artificial lakes / ponds to overcome seawater intrusion in aquifers and decline Water table [3]. Considering the effects of vertical recharge, flow density and the influence of boundary conditions on coastal aquifers [7]. The differences in salt concentration of seawater and river water, there will be a flow of liquid with a larger density to a smaller density. The distance or length of salt water intrusion is strongly influenced by river discharge and high tidal. At high tide, tidal currents will drive upstream salinity, while at low tide the river's flow will push the salt water downstream [4]. The seawater intrusion will be seen with various pumping scenarios to the aquifer. In the form of density contours, heads, and velocity generated at specified time stages [9]. The Darcy velocity and permeability on porous media (sand, gravel, soil and clay) different according to the length of the sample, at the same length of sample as the Darcy velocity decreases on the fine sand while in the gravel sand Darcy velocity increases, the hydraulic conductivity value or variation permeability coefficient [6].

3. MATERIALS AND EXPERIMENTAL PROCEDURES

3.1. Materials

The tool used in this research is Flume length 250 cm width 30 cm and height 40, camera, stationery, salinometers, ruler and other tools. The materials used in this research are Beach Sand from different location, cement, dye, freshwater and seawater, partition made of soil and cement mixture with ratio of 6:1, with 4 variation depth (D= 0, D= 2cm, D = 5 cm and D = 10 cm) and 3 variation thickness (B=0,5 cm, B = 1,00 cm and B = 2,00 cm)

The preparation of soil cement bulkhead in this research using soil derived from coastal and cement content (SC) whose cement content Each mixture with a certain amount of soil : cement (6 : 1), with dimensions, length 30 cm height 20 cm and 3 variations of thickness. The samples from the soil cement bulkhead will be tested for strength with unconfined compression test (qu) and CBR test.

3.2. Experimental Procedure

The study of texture sand beach site was investigated in the laboratory to determine the texture and composition: granular diameter (d = d50), and porosity (n)

a) Type of sand texture already known by Sieve analysis (k) as a reference to establish the aquifer texture model.

b) Made a partition model of soil cement with the ratio 6:1, the appropriate width of the channel and then inserted a sand model representing this coastal aquifer (according to the test sequence) into a rectangular flume with a width of 30 cm, height 40 cm and length 140 cm.

c) Flume is then filled with water upstream 20 cm (freshwater) and downstream (seawater) with high variations of 25, 20 and 15 cm.

d) As a first step, the experiment will be carried out with sand or aquifer model with a height of 40 cm and forming a 45° on the downstream.

e) Using natural condition and different height water level saltwater and freshwater, soil cement bulkhead by 3 variations depth of the bulkhead (D) and 3 variation thickness (B) to the saltwater level determines the intrusion length testing point on the downstream Aquifer.
The flow equation used natural condition or before bulkhead is:

\[ q = k \frac{d h}{L} A. \]  

where:
- \( q \) = discharge of freshwater (m³/s)
- \( k \) = permeability co-efficient (m/s)
- \( \frac{d h}{L} \) = seepage velocity (m/s)
- \( A \) = seepage area (cm²)

4. RESULT

4.1. Materials

In this research, laboratory test for the characteristic sand samples used, the result obtained that sand sample is white sand depth 0 - 2 m for water content test average 0.604% - 1.215%. For Specific gravity test in sand laboratory is 3.308 - 3.158. Porosity value 0.666 - 0.793
Saltwater seepage in coarse sand will be longer than seepage in medium sand and fine sand. This shows that the coarse sand is able to pass water faster because of its larger pores, seepage increased by 12.65% in medium sand and 29.98% in coarse sand. This is in accordance with research conducted Fujisawa et.al (2013) sand particles have relationship the seepage force.

Discharge measurements on variation types of sand (permeability) shows at Table 1. The results of this research using coarse white sand as media unconfined aquifer at coastal area

| Table 1 Saltwater Seepage Direct observation vs Empiric’s formula |
|-------------------------|-----------------|-----------------|
|                         | Sandy           |                 |
|                         | Permeability (cm/h) | q Out (ml/h) |
| Direct observation      |                 |                 |
| Coarse                  | 0.0025          | 0.0281          |
| Medium                  | 0.0008          | 0.0090          |
| Fine                    | 0.0003          | 0.0034          |
| Seepage's Empiric Formula |              |                 |
| Dupuit                  |                 |                 |
| Coarse                  | 0.0025          | 0.0774          |
| Medium                  | 0.0008          | 0.0260          |
| Fine                    | 0.0003          | 0.0074          |
| Schaffernak & Van Iterson |              |                 |
| Coarse                  | 0.0025          | 0.0149          |
| Medium                  | 0.0008          | 0.0021          |
| Fine                    | 0.0003          | 0.0002          |
| Cassagrande              |                 |                 |
| Coarse                  | 0.0025          | 0.0148          |
| Medium                  | 0.0008          | 0.0021          |
| Fine                    | 0.0003          | 0.0002          |

4.2. Performance of Soil Semen Bulk head To Reduce Saltwater Intrusion

Performance of insulation as a modeling of artificial barrier construction based on saltwater seepage obtained from laboratory test in static condition using channel model with 4 variation barrier depth and 3 variation thickness of bulkhead and using white sand as salt water seepage showed on Table 2

| Table 2 Effect Bulkhead Dimension To Reduce Intrusion |
|-----------------------------------------------|-----------------|-----------------|
| Depth Of Bulkhead D (cm) | Thicknes of Bulkhead B (cm) | Length Of Intrusion Lx (cm) |
| 0, 1, 2                  | 0, 1, 2          | 57.79, 50.03, 47.68 | 46.65, 46.11, 45.68 | 38.02, 27.00, 37.20 |
| 2, 4, 6                 | 0, 1, 2          | 53.12, 44.85, 41.29 | 43.43, 42.92, 42.43 | 32.76, 33.86, 32.27 |
| 5, 7, 9                | 0, 1, 2          | 46.98, 38.15, 33.29 | 39.74, 38.58, 37.24 | 31.49, 31.07, 30.46 |
| 10, 12, 14             | 0, 1, 2          | 36.85, 35.44, 30.42 | 30.96, 29.59, 29.21 | 25.03, 24.41, 23.35 |
4.3. Relationship Depth of Barrier with Length of Intrusion

If the bulkhead depth or high insulation increases then saltwater seepage will decrease. Conversely, if the condition of flow without insulation or depth of the bulkhead is reduced then the process of saltwater penetration into the aquifer will increase. The observation was done without insulation and using the soil insulation of cement with the depth of the bulkhead in this research used 3 variations that is $D_1 = 2$ cm, $D_2 = 5$ cm and $D_3 = 10$ cm. Effect of the depth of bulkhead to length intrusion shows in Figure 3.

![Figure 3](image-url)  
**Figure 3** Relationship depth bulkhead with length intrusion

Table 2 shows that the increase in the depth of the bulkhead causes the length of intrusion decreases. Percentage of intrusion length is calculated by the formula

$$P \% = \frac{L_x - L_o}{L_x} \times 100$$

The length intrusion value was obtained from experiments conducted in the laboratory showed in Figure 4.

![Figure 4](image-url)  
**Figure 4** Graph Relationship Depth of Bulkhead with Increase percentage Length of Intrusion

The graph shows the relationship between the increase in value depth of bulkhead ($D$) on the increase in percentage reduction of intrusion length ($P$) than without insulation. For $D = 2$ cm the value $P$ respectively increased 13.86%, 17.18% and 34.74%, for $D = 5$ cm value $P$ respectively increased by 6.91%, 14.81% and 33.64% and $D = 10$ cm percentage of reduction of intrusion length ($P$) respectively increased by 8.08%, 18.7% and 36.24%.
5. CONCLUSION
The results indicate that artificial barrier subsurface reduce saltwater intrusion: soil semen bulkhead can reduce the length of saltwater intrusion. Dimension bulkhead (depth and width) With increasing value insulation, While natural condition (without bulkhead) Length of intrusion \( (L_x) = 57.79 \text{ cm} \) and used bulkhead at thickness \( (B) = 0.5 \text{ cm} \) and \( (D) = 2 \text{ cm} \) the length of intrusion reduce 8.08\%, \( D = 5 \text{ cm} \) length of intrusion reduce 18.70 \% and \( D = 10 \text{ cm} \) length of intrusion reduce 46.24 \%.

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