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Experimental Study on the Impact of Filter layer Permeability on Revetment Stability under Wave Action

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Abstract

In the design of revetment engineering under wave action, to resist the wave action, the pattern of Top layer - Filter layer – Core(subsoil) is often adopted. In general, the structure of top layer is usually single discrete blocks, typically accropode blocks, four-leg square hollow blocks and barrier boards, and also acropode, riprap, paved rock blocks or concrete slabs where with smaller waves. Such top layer has been provided with many research findings on its stability and is widely used in engineering. Setting a filter layer between the top layer and the lower dike core mainly has two functions: (1) giving certain permeability, to minimize the hydrodynamic load directly acting on the lower foundation soil; (2) giving certain hydraulic tightness, to prevent fine sediment of the lower foundation soil being rushed out. This paper is focused on a special filter layer with geotextile as its upper structure and coarse aggregate as its lower structure. By simulating geotextile with different permeability and coarse aggregate with different size, The pressure of top of cover layer and the down side of the geotextile is tested under wave actions, and compared with theoretical analysis, in this way, how the permeability of geotextile impacts the stability of top layer is studyed. The research shows that when the lower coarse aggregate under the geotextile has high permeability and the geotextile's permeability get poorer, the uplift force to the top layer will be increased under wave action, which will cause damage to the top layer when it si greater than the vertical component force of the block gravity under the water .

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Keywords:Revetment, Wave, Filter layer, Geotextile , Permeability, Uplift force

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1. Preface

The revetment engineering for estuary, inland lake, reservoir, some channels and inland river is often borne by the action of wave and flow. To prevent such action from damaging bank slope, cover layer-filter layer-subsoil is often adopted for protection. See Figure 1 for the main structure. In the cover layer-filter layer-subsoil structure, the external top layer is generally rocks, blocks or asphalt, bearing the direct action of wave and water flow and increasing the load of lower layer. The filter layer is beneath the top layer which is usually single-layer or multi-layer gravels and sand, providing support for the top layer. For permeable structure, the filter layer, on one hand further relieves the wave and flow action on subsoil; on the other hand, it prevents the undermining of subsoil through the decrease of its geometric bore diameter. As the geotexitile has a small bore diameter and is well permeable, it is widely adopted in filter layer. Most of geotextiles are placed between the sand layer and soil layer of the filter layer, but some are between the top layer and sand layer [1] [2]. For such a structure, the permeability of filter layer has a great influence on the stability of cover later under wave action. In this paper, by simulating geotextile with different permeability and coarse aggregate with different size, the pressure of top of cover layer and the down side of the geotextile is tested under wave actions, and compared with theoretical analysis, in this way, how the permeability of geotextile impacts the stability of top layer is studyed .

Gerrit J. Schiereck [3], de Groot [4], A. M. Burger [5], Adam Bezuijen, Mark Klein Breteler [6] have made a lot of researchs about how the permeability of filter layer influence the stability of the toplayer blocks. This thesis conducts research on the basis of these research achievements

2. Physical modelling experiment

In a reservoir dike engineering located in north china, in order to protect the wind wave destroying the slope, top layer-geotextile-sand layer-subsoil is adopted. For such a structure, there had been a sudden destroy of top layer blocks in heavy wind waves after being used for several years. Field investigation shows that geotextile below the top layer is clogged. Experiments show that this may be the cause of the engineering failure. Physical model tests is carryed out to study this. See Figure 5 for the slope section in the experiment, with a gradient of 1:3, the porous blocks(100×100×14mm) with 5 hole diameter of 18mm are used as cover layer. The filter layer includes the upper geotextile and lower sand layer with a thickness of 50mm, below the sand layer is subsoil. The depth of water in front the slope section is 500mm. See Table 1 for wave parameters in the experiment, including 5 different wave periods, which also have 5 different wave height. Only regule wave is tested in this experiment.

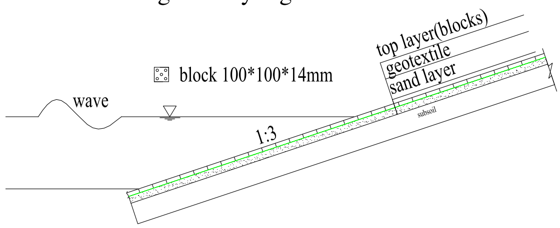


Figure 1 Sectional View of Slope in the Experiment

In fact, the weight of geotextile is negligible compared with top layer blocks, and so its effect on top layer mainly lies in its permeability coefficient. After been used for years, the pore of geotextile will be blocked by fine particles in water, leading to the decrease of its permeability coefficient. In contrast, the experiment also chose a geotextile with relatively smaller permeability coefficient which is close to that of geotextile in actual engineering after being used for several years. The influence of particle's diameter of sand layer was also take into account in the experiment, so sand and fine sand were chosen in the modelling experiment. See Table 2 for the specific parameters of geotextile and filter layer in the experiment.

Table 1 Wave Conditions in the Experiment

T=1.2s		T=1.4s		T=1.6s		T=1.8s		T=2.4s	
H(cm)	ξ	H(cm)	ξ	H(cm)	ξ	H(cm)	ξ	H(cm)	ξ
9.8	1.57	10.2	1.85	10.1	2.14	10.3	2.38	11.6	2.87
12.0	1.39	11.9	1.71	11.9	1.97	12.2	2.18	14.0	2.62
14.0	1.39	13.9	1.58	14.2	1.80	13.9	2.04	16.3	2.42
15.6	1.31	16.0	1.46	16.0	1.69	16.3	1.88	19.0	2.24
17.8	1.21	18.3	1.36	18.1	1.59	18.3	1.78	22.2	2.08
20.4	1.12	20.0	1.30	20.0	1.51	19.9	1.70	25.3	1.95

Table 2 Filter layer in the Experiment

Geotextile	1	k=3.5×10-2cm/s	h=0.4cm
	2	k=3.2×10-1cm/s	h=2.0cm
Filter layer	Sand	k≈1.0×10-3cm/s	d_{50}=0.37 mm
	Fine sand	k≈1.0×10-2cm/s	d_{50}=2.73 mm

The experiment measured the pressure of different layer: pressur 1, at the down side of the top layer (upper side of the geotextile); pressur 2, lower part of the geotextile (upper part of the sand layer); pressur 3, lower part of the sand layer under wave action. See the measurement point arrangement in Figure 2. As the uplift force caused by waves may lead to damage of top layer, measures were taken to fix the top layer during the experiment so as to prevent it from falling off under wave action.

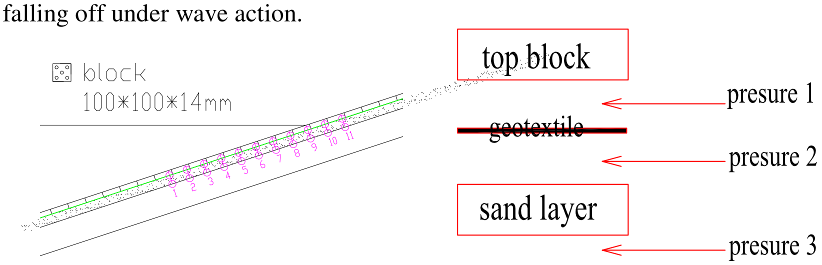


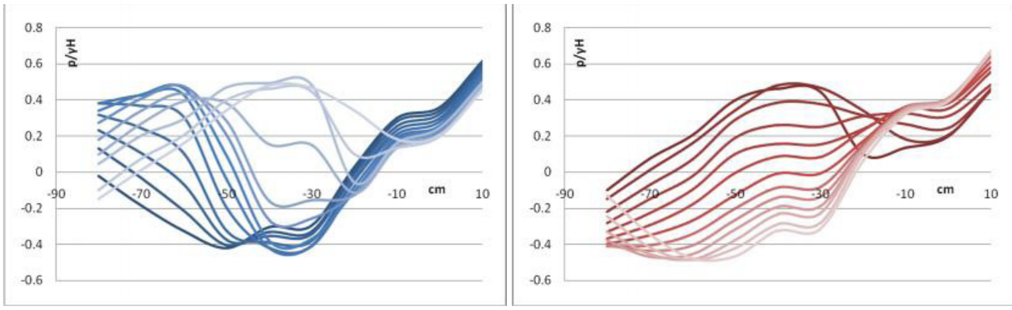
Figure 2 Pressure Measurement Point Arrangement at the lower part of Top layer/upper part of Filter layer and lower part of Filter layer

3. Experiment result analysis

Under wave action, waves climbe up the slope, then fall back after breaking. Figure 3 show the change process of the pressure of waves under the top layer on slope. The filer layer conditions for this experiment is geotextile 1 and sand filter layer.

In the aforesaid process, the pressure distribution of waves at the lower part of top layer(pressure 1), upper part of sand layer(pressure 2) and lower part of sand layer(pressure 3) on slope can be found in Figure 4.

It thus can be seen that the negative pressure of top layer is obviously different from that of the filter layer and there exists uplift force in the filter layer acting on the top layer.



a. Breaking while ascending b. Falling back after Breaking

Figure 3 Slope Pressure Process under Wave Action (H=12cm,T=1.2s; t=0~0.6s,Δt=0.05s)

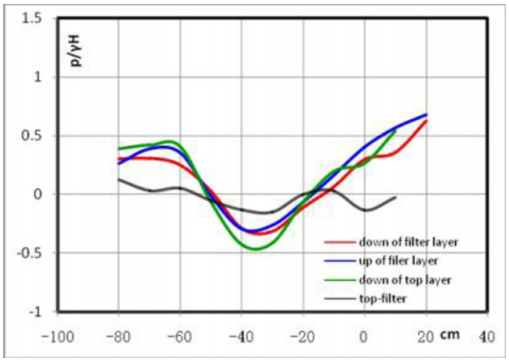
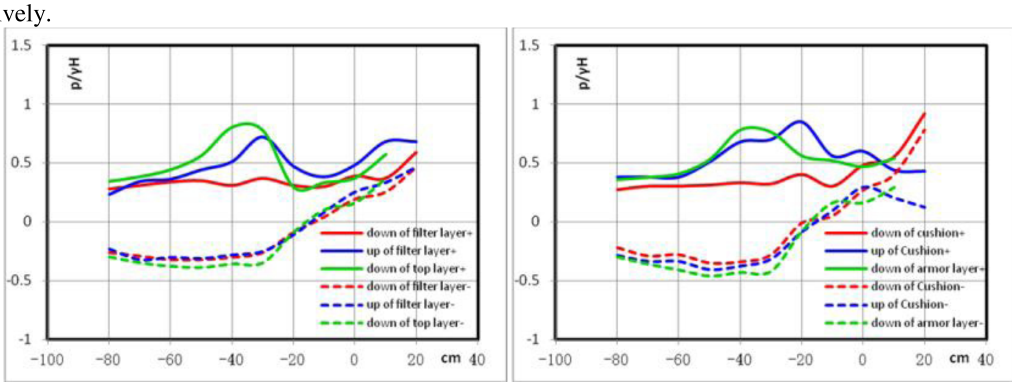


Figure 4 Pressure Distribution on All Layers of Slope under Wave Action(H=12cm,T=1.2s;t=0.24s)

Under wave (H=12cm, T=1.2s) action, the maximum positive pressure and negative pressure distributions at the bottom of top layer, top of filter layer and the bottom of filter layer of geotetile 1 or 2 are as shown in Figure 5 respectively.

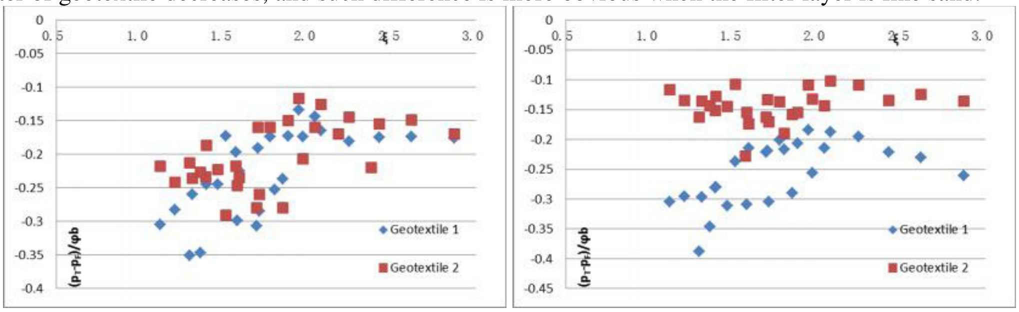


a. Geotextile 1 b. Geotextile 2

Figure 5 The Maximum Positive Pressure and Negative Pressure Distributions (Sand Filter layer, H=12cm,T=1.2s)

When the filter layer is composed of sand and fine sand, geotextile 1 and geotextile 2 are adopted correspondingly. See Fig. 6 for the maximum relative pressure difference between the bottom of top layer and top of filter layer for each experiment group. Through comparison, it's found that the relative uplift force of geotextile

1 with poorer permeability acting on the top layer is greater than that of geotextile 2 when the permeability parameter of geotextile decreases, and such difference is more obvious when the filter layer is fine sand.



a. Geotextile 1 b. Geotextile 2

Figure6 Distribution of Pressure Difference between the Top Layer and Filter layer Corresponding to ξ when the Filter layer Is Sand

When the filter layer is composed of sand and fine sand, geotextile 1 and geotextile 2 are adopted correspondingly. See Figure 6 for the maximum relative pressure difference between the bottom of top layer and top of filter layer for each experiment group. Through comparison, it’s found that the relative uplift force of geotextile 1 with poorer permeability acting on the top layer is greater than that of geotextile 2 when the permeability parameter of geotextile decreases, and such difference is more obvious when the filter layer is fine sand. When the uplift force is greater than the vertical component force of the block gravity under the water, the top layer will be damaged.

4. Computing of water pressure in filter layer

Next, the pressure under the geotextile will be calculated by theoretical analysis.

The stability of top layer and filter layer will be influenced when waves are falling back and close to break. At this moment, as the waves have fallen back to the lowest point and the water flow movement inside the filter layer is relatively slow because of the influence of permeability, there exists internal and external water pressure difference. At this moment, the uplift force acted on the top layer is thought to be the maximum.

The piezometric head on top layer ϕb is calculated by formula (2); H_s the significant wave height, the other parameters see Fig.7.

$$\xi_{op} = \tan\alpha \Big/ \sqrt{\frac{2\pi H_s}{gT_p^2}} \tag{1}$$

$$\frac{\phi_b}{H_s} = \min\left(\frac{0.27\xi_{op}}{(\tan\alpha)^{0.75}}; 2.5\right) \tag{2}$$

$$\tan\theta_f = 2.25 \tag{3}$$

$$\theta_h = \frac{45^\circ}{\sqrt{\xi_{op}}} \tag{4}$$

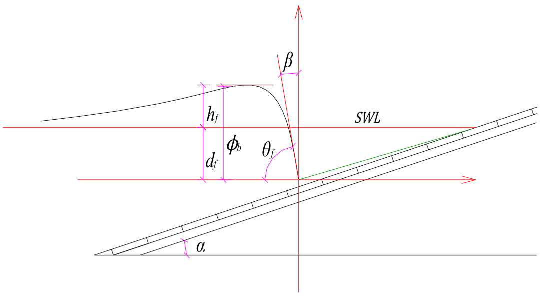


Figure 7 Calculation of the piezometric head on top layer ϕb

Water flow movement in filter layer is considered to comply with Forchheimer formula:

$$I = au + bu^2 + cu^{'} \tag{5}$$

Regarding the determination of coefficients in the formula, M. R. A. van Gent [7] conducted a careful research and the test results show that the laminar flow coefficient is different from the turbulent coefficient in the formula under the action of steady flow and reciprocating flow. For reciprocating flow, turbulent influence is even greater. In the meantime, the research shows that the acceleration item has little influence on general gravel filter layer.

The internal and external water pressure difference caused by different permeability of top layer and filter layer is usually reflected by leakage length:

$$\Lambda = \sqrt{\frac{k_F d_F d_T}{k_T}} \tag{6}$$

Supposing that wave pressure in top layer is $p_T(x,t)$ and water pressure in filter layer is $p_F(x,t)$, if the seepage flowing through the top layer complies with the Darcy's Law, the seepage velocity along the dx section of the slope is:

$$v = k_T \frac{p_T(x,t) - p_F(x,t)}{D} \tag{7}$$

Supposing that the bottom (x=0) of filter layer is impermeable, the seepage discharge within x is:

$$Q = \int_0^x v dx \tag{8}$$

When the water penetrating the top layer makes horizontal movement in the filter layer, the seepage discharge in the filter layer at x is:

$$Q = -k_F \frac{\partial P_F(x,t)}{\partial x} d \tag{9}$$

From (8) and (9), it can be concluded:

$$\frac{\partial^2 P_F}{\partial x^2} = -\frac{k_T}{Ddk_F}(p_T - p_F) \tag{10}$$

It is the same with the formula obtained by Wolsink.

As regards (10), we adopt a solution different from Wolsink's, assuming $p_T(x,t)$ conforms to such a model (See Figure 8).

$$p_T\left(x,t\right)=\frac{\phi_T}{2}\sin\frac{2\pi x}{l}\sin\frac{2\pi t}{T}\quad (0<x<l/2) \tag{11}$$

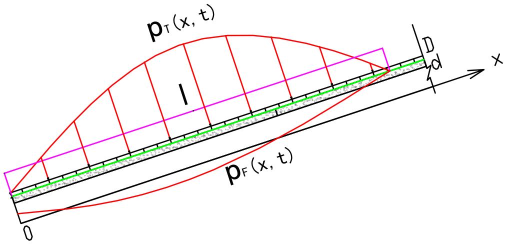


Figure 8 Pressure Distribution in Top Layer assumed in (11)

In consideration of the boundary condition, when x=0, it can be drawn that:

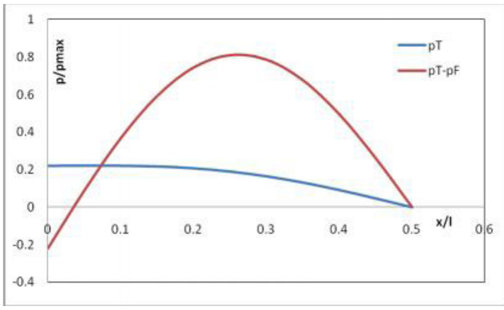
$$\frac{\partial p_F}{\partial x}=0 \tag{12}$$

and, when x=1/2, without regard to the boundary's influence on outflow, supposing:

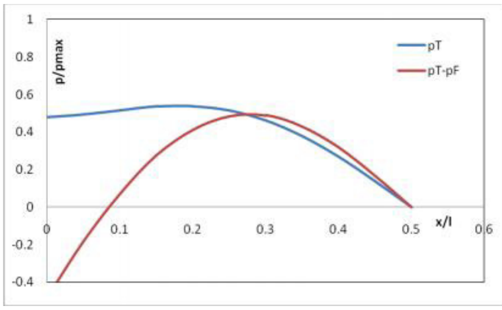
$$\frac{\partial^2 p_F}{\partial x^2}=0 \tag{13}$$

According to these conditions, water pressure distribution in filter layer is:

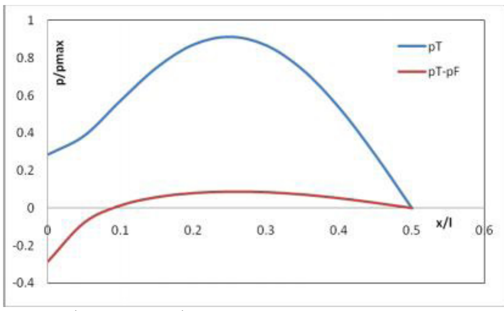
$$p_F=\frac{\phi_T}{2\left(1+\frac{4\pi^2\Lambda^2}{l^2}\right)}\left[\sin\frac{2\pi x}{l}-\frac{2\pi}{l}\frac{\Lambda}{1+e^{l/\Lambda}}\exp\left(\frac{x}{\Lambda}\right)+\frac{2\pi}{l}\frac{e^{l/\Lambda}\Lambda}{1+e^{l/\Lambda}}\exp\left(-\frac{x}{\Lambda}\right)\right]\sin\frac{2\pi t}{T} \tag{14}$$



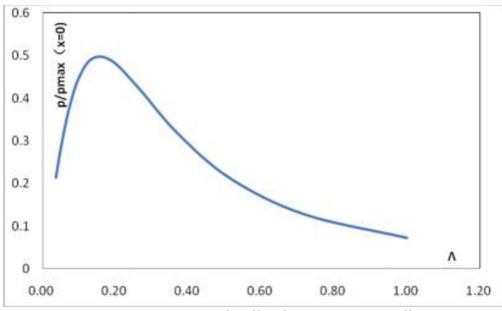
a. When Λ=0.5, l=1m



b. When Λ=0.2, l=1m



c. When Λ=0.02, l=1m



d. When x=0 pressure Distribution Corresponding to Λ

Figure 9 Pressure Distribution in Filter layer Concluded in Formula (14)

Comparing formula (15) with (12), we can qualitatively see that the main pressure difference between the top layer and filter layer is $1/\left(1+4\pi^2\Lambda^2/l^2\right)$. When Λ is relatively high (the permeability of filter layer is better than that of top layer), the pressure in filter layer is smaller than that of top layer, the pressure difference is large and the uplift force acting on top layer is great, vice versa; l is related to the wave height H and breaking wave parameter ξ.

When Λ=0.5, Λ=0.2 and Λ=0.05 (l=1m), the piezometric head in filter layer computed in formula (14) and the piezometric head difference between the top layer and filter layer are as shown in Figure 9. It thus can be seen that the uplift force acting on the top layer decreases as Λ decreases; additionally, it is the impermeable boundary where x=0. When Λ=0.2, the pressure in the filter layer is the maximum, because the permeability of top layer is too high when Λ is relatively small, resulting in a low pressure inside and outside the filter layer; with the increase of Λ, the permeability of top layer decreases, resulting in the expansion of high osmotic pressure to where x=0, so the pressure continuously increases; when Λ is high, the permeability of filter layer is high. As where x=1/2 is an open boundary, water penetrating through the top layer will soon ooze through the boundary. Consequently, the pressure transmitting to where x=0 is small.

The actual boundary at x=1/2 is different from that assumed in formula (13). In fact, where x>l/2, the filter layer makes $\partial^2 p_F/\partial x^2 > 0$. Therefore, under the positive pressure action, where the pressure inside the filter layer is 0, x >l/2; under negative pressure action, where the pressure inside the filer later is 0, x<1/2.

5. Main conclusions

- For top layer-filter layer-subsoil revetment structure under wave action, when the permeability of top layer is poorer than that of filter layer, there will be great uplift force inside the filter layer acting on the top layer.
- The parameter $1/\left(1+4\pi^2\Lambda^2/l^2\right)$ can be used to conduct quantitative comparison between the water pressure inside the filter layer and wave pressure outside the top layer.
- In the using process of top layer-geotextile-filter layer-subsoil revetment structure, as the clogging of top layer or geotextile may result in the decrease of top layer's permeability, the uplift force of filter layer may increase under wave action. Especially when the permeability of filter layer is good, this uplift force change is more obvious. Therefore, the design shall allow for the clogging in practical use and the thickness of top layer shall thus be increased appropriately.

References

[1] M.Klein Breteler and Bezuijen, Design criteria for Placed Block Revetments, Dikes and Revetments(Krystian W. Plarczyk), pp217-248.
[2] Yan Tongsheng. Summary and Discussion on Upstream Slope-protection for Reservoirs on Plains. Water Resources Science and Technology of Shandong, 1996, pp14-17.
[3] Gerrit J.Schiereck, Soil-Water-Structure Interactions, Dikes and Revetments (Krystian W. Plarczyk), pp101-112.
[4] de Groot, M. B., A. Bezuijen, A. M. Burger, J.L.M.Konter, The interaction between soil, water and bed or slope protection, Modeling Soil-Water-Structure Interactions (Kolkman et al.), pp183-197.
[5] A. M. Burger, M. Klein Breteler, L.banach, A. Bezuijen, K. W. Pilarczyk, ANALYTICAL DESIGN METHOD FOR RELATIVELY CLOSED BLOCK REVETMENTS, J. Waterway, Port, Coastal, Ocean Eng. 1990.116:525-544.
[6] A. Bezuijen, M. Klein Breteler, DESIGN FORMULAS FOR BLOCK REVETMENTS, J. Waterway, Port, Coastal, Ocean Eng. 1996.122:281-287.
[7] M. R. A. van Gent, POROUS FLOW THROUGH RUBBLE-MOUND MATERIAL, J. Waterway, Port, Coastal, Ocean Eng. 1995.121:176-181.