Wave Run-Up and Stress Imposed On a Permeable Coastal Bed Sample of the Caspian Sea

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ABSTRACT

This research aims to reconsider the wave run-up and eulerian schematic of flow contours and the fluid movement path in the sediment sample gathered from southern Caspian Seashore bed, using experimental method in wave flume. The general characteristics of flow depend on the kind of bed structure, the bed shear tension, vertical velocity profile and the permeation velocity, could be changeable. While, because the increasing of water surface height, the fluid penetrates bed, and consequently the suction phase happens within the bed. Through this condition the flow contours approach the bed and the mean velocity accelerates near the bed, and then the tension rises about 3 times.Because the decreasing of water surface height, the fluid permeates out from the bed and the injection phase happens, so that the flow contours get away from the bed and the mean velocity falls down near the bed , so the tension slakes about 80%. This studyuses 3 waves with a sharpness ranges from 0.01 to 0.06.The wave run-up has been measured using the wave height recorders which have been installed on a ramped shore with a constant slop of 1:5. By using a camera under water and also color injection into the bed, the flow contours and movement path of fluid in the sample of Caspian Sea, the permeability ranges have been drawn. Meantime, the flow velocity is estimated in two positions including near the bed surface and the bed deep. Through the relative non-dimensional permeation velocity ($\tilde{U}=Vz/Vx$), it is shown that in a given wave frequency, by increasing velocityin the suction phase, the tension imposed on the bed is risen up, whiles by increasing the relative velocity in injection phase the tension imposed on the bed is fallen down.

1. Introduction

A Fluid current depends on the bed permeability over a porous surface such as, sandy bed of Caspian Sea. For calculation of the bed permeability, the hydraulic conductivity of bed sediments and hydraulic gradient of fluid are of high importance. Regarding the literature reviews on the permeability experimental studies except to this research and an investigation done by Beidokhti et al, (2003) [1], there is a little developed works in this study field.Conley and Inman (1992) [2] have done some field studies about the effects of bed structure on the wave behavior, also they found that the formation of the shore bed depends on the tension variations. The effect of bed permeability on wave characteristics over a shore has been studied by Conley and Inman (1994) [3]. One of the results derived by analysis of water flows over a permeable bed that is conducted by Conley and Inman (1994) [3] and Beidokhti et al, (2003) [1], has been shown in Figure 1.

Regarding this graph, it is notable that the high suction velocity could lead to increase the tension imposed on the bed and conversely, through the high injection velocity, the tension could be decreased near the bed. Meantime, the suction velocity indicates a direct connection to the permeability of bed and pressure gradient, whiles there is a converse relation with the fluid viscosity. Conley and Inman`s experiment is done on a horizontal bed through fluctuation of the fluid Head, with a constant frequency.

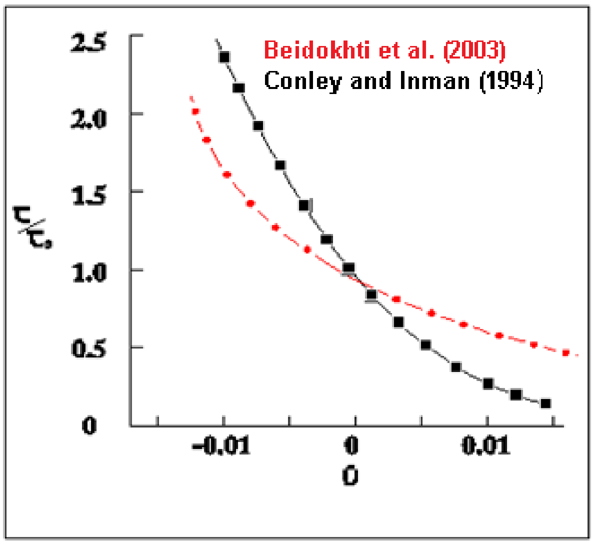

Figure 1.the results derived by Beidokhti et al.,(2003) and Conley and Inman (1994).
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Villarroel-Lamb et al, (2014) [4] conducted the series of experiments through a Hunt-type runup formulation and Indicated that there is a clear relationship between bed permeability and the maximum wave run-up. Hughes (2004) [5] developed a study to provide an estimation technique that was as good as existing formulas for breaking wave run-up and better at estimating nonbreaking wave run-up. For irregular waves breaking on the slope, a single formula for the 2% run-up elevation proved sufficient for all slopes in the range 2.3≤tanα ≤1.3. Antonia et al. (1990) [6], conducted some researches on the effect of surface suction to vortex boundary layer and separation event. This experiment investigates the effects of suction and injection phases on the surface tension of a ramped bed of Caspian Sea sediments affected by run-up and rundown. These effects on the wave run-up also are considered. According to this fact that in the experimental models to determine the extent of run-up and rundown, and in general the hydraulic reactions of breakwaters and shore structures, the permeability of bed is assumed to be ignorable because of the selection of the common experimental scales, thus, conducting such experiments on the samples provided from Caspian Sea shore bed, in order to consider the effects of the bed permeability could be necessary.

2- Physical foundations

While the waves approach to the shallow zone of sea (near the shoreline), they rise and consequently breakdown after collision to the shoreline. Following the wave-break, and the resulted balance with hydrostatic force, the water surface gets raised. The rising of water surface is called run-up (Figure 2).

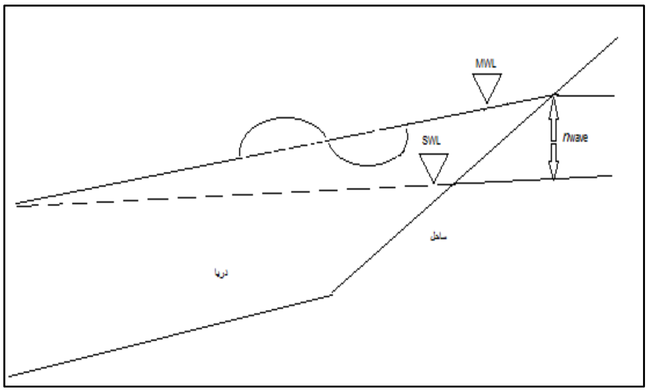

Figure 2. Wave Run-up

The run-up hydraulic reaction of wave occurs during the wave collision to the shoreline. At this moment, the waves – because of having the kinetic energy- climb the ramped shore, and so, the vertical distance of water level fluctuation on top of the water table, is the so called the wave run-up (Figure 3-A).
When, the kinetic energy fall to zero , by the existing potential energy and the fluid integration, the wave moves downward from shoreline and the hydraulic reaction of wave rundown occurs. The vertical distance of water level fluctuation under the water table, is the so called the wave rundown (Figure 3-B).

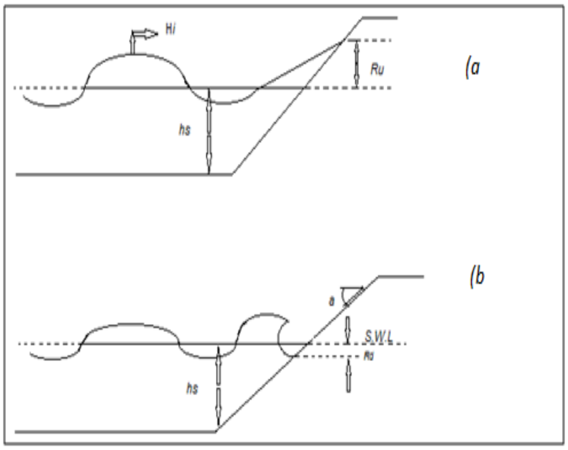

Figure 3; a) wave run-up, b) wave run-down

Wave run-up and rundown impose the positive and negative pressure on the shore bed respectively. In the case the bed is permeable, through the wave movement toward shore and the hydraulic reactions of wave run-up and rundown on the ramped shore, some currents could be generated within the shore bed. The above mentioned currents penetrate the bed, but the interactions with the objects over the bed and the consequent damping, limit their penetration by a certain deep.
The water pressure gradient is considered the cause of above current, and the generated velocity gradient will be different based on the bed gradation and permeability. Friction of shore currents by the bed permeability leads to lose the wave energy as

reduction of run-up and rundown and also manner of wave break.To show the manner of wave break and the wave interaction with the ramped shore, the similarity parameter of wave break or the non-dimensional number of Airybaren has been used (Figure 4).

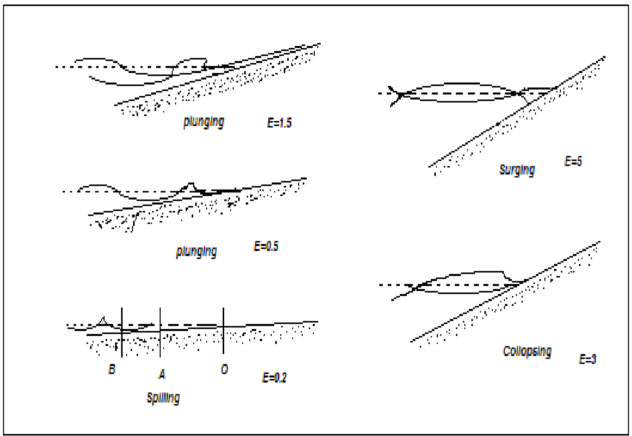

Figure 4; Breaking similarity parameter

The similarity parameter of break is defined as follows: $\xi = \frac{\tan a}{\sqrt{S}}$ (1)

In the above equation, "S" as the sharpness of wave is defined by the following relation: $S=\frac{H}{L}$ (2),

and here "H" is the height of wave and "L" is the length of wave.

3- Experimental phases

To consider the permeability effect of Caspian Sea shore bed on hydraulic reactions of wave, the laboratory model has been applied. The wave flume dimensions are as follows: 45m length, 6m width and 1.5m depth. In order to prevent production of the horizontal waves, the flume is divided into 3 sections so that the middle flume has 26m length, 1.5m width and 1.5m depth. All experiments have been done on an artificial shore at the outset of middle flume. The waves are generated by using a piston paddle installed at the end of flume. The artificial shore has been made inside a box with dimensions of 2.5m length, 1.5m width and 0.65m depth and a constant slop of 1:5.This box is filled by the gravels gathered from southern coasts of Caspian Sea with different permeability. The sandy and gravel materials are taken in consideration based on the soil mechanic experiments by 3 different permeability (including 3 water conductivity coefficients: 0.079, 0.075 and 0.079 cm/s). During the experiments, 6 waves have been generated and moved towards the artificial shore. The waves which hit the shore have sharpness ranges from 0.01 to 0.06. During the interaction of wave and shore, a camera has been installed under water on the shore bed, to track and record the fluid current which is colored. The velocity of the current has been estimated by measuring the relation between time and distance of the current movement. To record the wave run-up and rundown, 2 wave height recorders have been installed on the ramped shore bed. In total about 65 experiments have been done that their outputs are shown by graphs and tables.

3-1- Measurement errors

The measurable parameters through the experiments include: wave run-up, wave height, waves frequency, current velocity within the bed. The measurement errors of above parameters during the experiments have been shown in table 1.

Table 1; The errors derived through measurements in the experiments

three depths of 5 , 10 and 15 cm.	The flow speed in the bed (suction and injection)	The flow speed of wave run-up and run-down	Wave period	Wave height	Wave run-up	Parameters
V1 , V2, V3	Uzs , Uzi	UR , Ud	T	Hw	R	variable
cm/s	cm/s	cm/s	s	cm	cm	unit
0/04±	0/02±	0/025±	0/02±	0/03±	0/2±	Error

4- The Findings

4-1- Effect of bed permeability on the wave run-up

In this section, the graphs of the wave relative run-up (as non-dimensional, R/H) based on the wave sharpness and the similarity break parameter, has been shown. Also, the current velocity of bed and the effects of injection and suction velocity on generated tension have been considered.

By the figure 5, the wave relative run-up according to the wave sharpness is shown, for the Caspian Sea permeable beach through the measurement points and their fitting line.

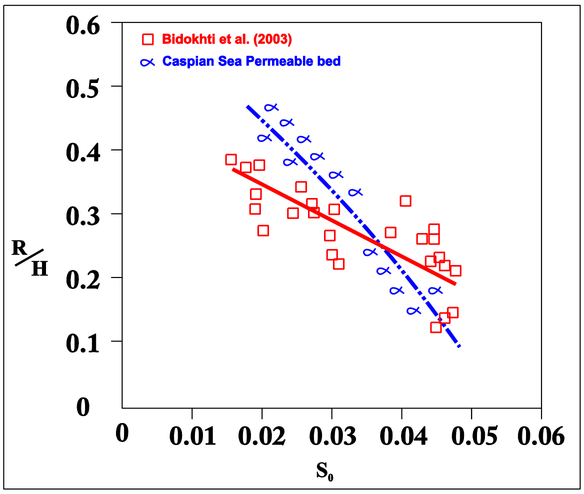

Figure 5; relative wave run up according to the wave sharpness for the permeability of Caspian Sea beach

Figure 6, compares the wave relative run-up according to the wave sharpness, between permeable beach of Caspian Sea with the permeability coefficient about 0.079, and the experimental beach in the study of

Beidokhti et al, (2003) [1] by their best fitting lines. Both studies illustrated that the permeability significantly causes high reduction of wave run-up, especially for the waves with poor sharpness. Actually this finding affirmed the result derived by the study of Beidokhti et al. [1].

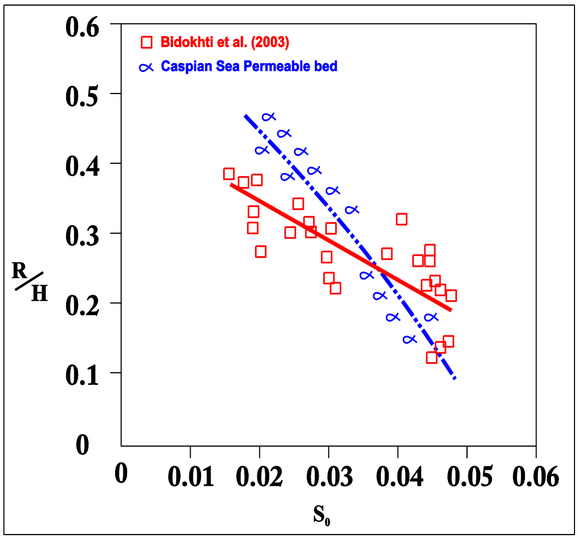

Figure 6; comparing of relative wave run up according to the wave sharpness over the Caspian Sea beach with the permeability coefficient about 0.079 and the study of Beidokhti et al (2003)

4-2- The effect of bed permeability on the bed currents

Reviewing the film record of the colored water movement, the effect of bed permeability on the current over the bed has been studied. The method used was based on the colored water movement and the calculation of the general current velocity over the bed in three positions: near the surface, middle and depth of the bed (Figure 7). Table 2, includes the waves height and frequency parameters along with the current velocity over the bed. The results derived by film analysis illustrated that by decreasing the radius of curvature in the current track, the bed permeability is getting decreased. Meantime, in the high depth the radius of curvature could be decreased also, as this finding illustrates that the strength of bed versus the fluid movement, gets increased by high depth and poor permeability.

Table 2; the information of measurements of the flow speed within the Caspian Sea bed

Experi	Permeability	Wave	Flow speed	Flow speed within the bed: Speed at depth of 5 cm. V1 (cm/s)	Speed at depth of 15 cm. V1 (cm/s)
1		9/5	1/95	1/2	1/96
2		9/1	1/2	1/11	0/99
3	(0/079)	8/4	1/55	1/16	1
4		9/1	1/04	1/12	0/95
5		8/3	1/1	1/1	0/93
6		9	1/09	1/38	0/91

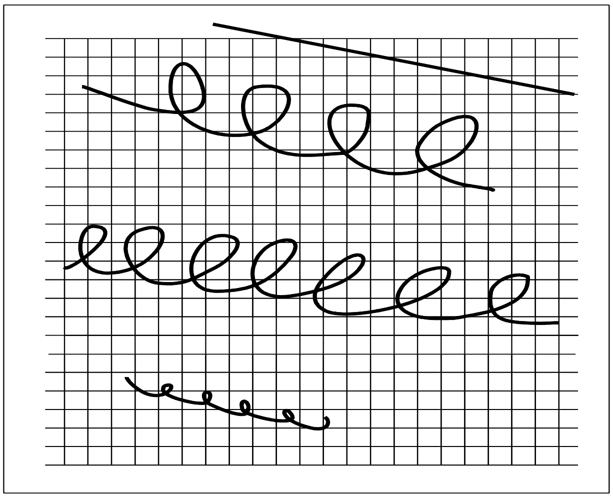

Figure 7. Track of injected color in three points respectively at 5cm, 10cm and 15cm from bed surface for the shore bed of Caspian Sea sample.

4-3- The effect of bed permeability on the tension imposed over the bed

As before mentioned, while the fluid penetrates/transpires the bed respectively a suction/injection process occurs. By studying the current tracks, U-suction and U-injection have been measured through different experiments for the permeability coefficient of 0.079. In the laboratory environment and during wave run-up/rundown, the horizontal velocity is the same run-up/rundown velocity, as defined the bed suction/injection respectively. Regarding the researches developed by Canli and Innman (1994) [3], and introducing the non-dimensional parameter (Ũ=Vz/Vx), this parameter is defined as following relations:

$$\tilde{U}zi=\frac{U\ injection}{U\ rundown}\ \text{and}\ \tilde{U}zs\frac{U\ suction}{U\ runup} \qquad (3)$$

For all experiments, it is calculated that Ũzs and Ũzi are the same, regarding the absolute values. The findings are presented by table 3.

Table 3; the measurement of different speed parameters

Experiment No.	$U_{suction}$ (cm/s)	$U_{injection}$ (cm/s)	U_{runup} (cm/s)	$U_{rundown}$ (cm/s)	$\tilde{U}zs=\frac{Usuction}{Urunup}$	$\tilde{U}zi=\frac{U\ injection}{Urundown}$
1	-1/9925	1/0127	47/3921	25/4484	-0/0567	+0/042
2	-3/129	2/8028	32/874	20/34	-0/0618	+0/0670
3	-1/058	2/4680	20/427	16/525	-0/0756	+0/0878
4	-3/584	2/756	21/4316	16/815	-0/1487	+0/1068
5	-4/565	2/977	20/2176	14/5394	-0/1267	+0/1239
6	-25/8567	3/2454	20/5271	15/2062	-0/2328	+0/1328

Beidokhti et al`s observations (2003) [1] verified that in a wave with constant frequency, by increasing the suction rate the bed tension in a permeable condition (t) comparing to the bed tension in a impermeable condition (t0), namely t/t0, is getting increased. Whiles, by increasing the injection rate the relation (t/t0) gets decreased. In the present investigation this problem has been studied according to 3 constant frequencies for the shore bed of Caspian Sea sample, and the results are shown by figure 8.

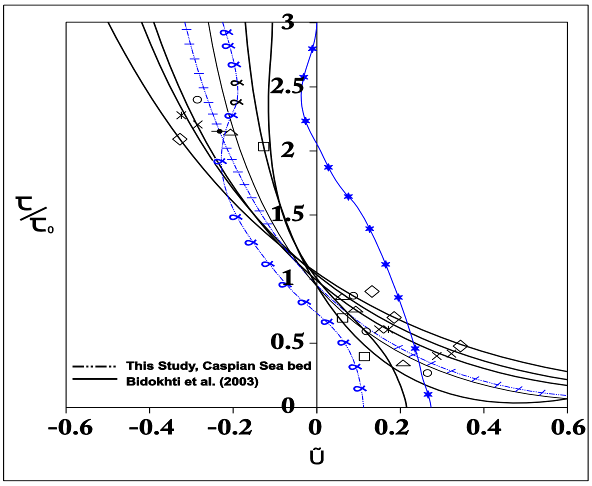

Figure 8; non dimensional parameter (Ũ) graph according to t/t0

5 – Results

The comparison between the results derived from Beidokhti et al`s experiments and the results of present experiments (Figure1), about the tension imposed on the bed, indicates that there is a similarity among the tension variations and the non-dimensional velocity through both studies.

Note, Canli and Inman (1994) [3] had done the experiments for a horizontal bed with different permeability, through one wave frequency only, and Beidokhti et al, 2003 [1] developed the experiments for an artificial sediments with different permeability, through 6 wave frequencies, whiles in the present investigation, the experiments have done on the samples of the Caspian Sea bed through 3 wave frequencies. The results obtained show that the reduction of relative tension up to about 80% in the injection phase was significantly evident, whiles in the suction phase increasing of relative tension is notable by 3 times (Figure 9). These intense variations illustrate the effect of bed permeability on tension, so that it should be taken into consideration in the natural conditions. It should be noted, the results obtained about wave run-up variations on the impermeable bed are pretty similar to the results of Ahrenz (1981) [7] so that in both of them the wave run-up height over the impermeable bed recorded with high ranks.

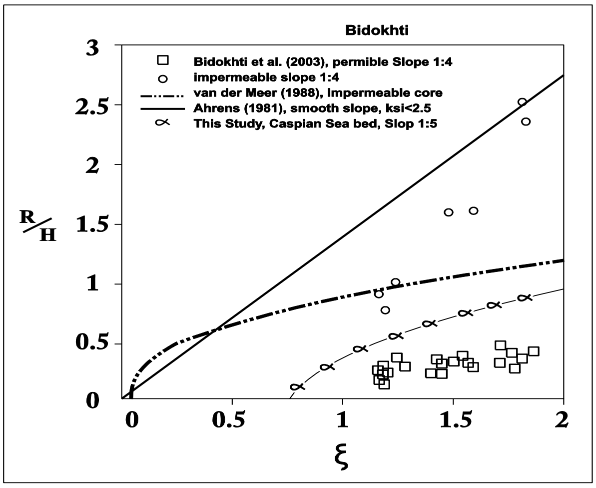

Figure 9; comparing the results of relative wave run up

6- Conclusion

The velocity of the current is getting decreased by poor permeability and deepening of the bed in the sample of Caspian Sea bed. Based on the observations of this experiment the velocity of the current within the bed does not relate to the wave frequency and the general line of current within the bed follows the water level. Vertical track of the fluid movement because of positive and negative imposed pressures on the bed (generated through wave run-up and rundown) completely depends upon the wave height and head. The fluid movement tracks as incomplete spiral lines parallel to the water level move towards outside.

In a wave cycle, the suction and injection phenomena are observed inside the bed. So that, by increasing/decreasing the head in result of wave run-up/rundown and imposing the positive/negative pressure on the bed the suction/injection occurs respectively. About the effect of permeability on tension imposed on the bed,it should be noted by increasing the suction velocity the tension on the bed is getting increased up to 3 times, whiles by increasing the injection velocity the tension on the bed is getting decreased about 80% , both phases (suction/injection) occur through approaching / receding of the vortex boundary layer to the bed. The variations of tension on the vortex boundary layer near the bed have a significant Importance.

The Increasing of bed permeability lead to decrease the wave run-up by 4 times and higher sharpness of wave also could decrease the wave run-up. Poor permeability in the sample of Caspian Sea bedincreases the wave run-up as it is evident on the permeable bed. Different permeability in proportion to the wave sharpness increase did not indicate a physical impact on wave run-up decrease.

Wave run-up from the ramped impermeable shore bed, as it is presented in the previous study,indicated of low ranks compared to the impermeable horizontal shore bed [8,9 and 10].

In a given permeability of the Caspian Sea bed with a specific wave frequency, by changing the wave height there is not any changes at U parameter , namely the relation of Ũ=Vz/Vx, has been considered independent from the wave height. Through a specific wave frequency it is found that by increasing Uzs the ratio of t/t0 is getting increased, whiles by increasing Uzi the ratio of t/t0 is getting decreased, such as the obtained results by Beidkhti et al (2003) [1]. Thus, regarding the considerable effect of bed permeability on the tension imposed of bed, it is necessary these effects to be taken into consideration through the applied researches.

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