

# Collective Review in Particular Reference to Soil Erosion around Maritime Structures, Effects of the Angle of Wave: Attack on Coastal Areas Formation and Variation on Transport Rates

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**Abstract** Hydraulic structures cause disturbances in uniform flow and sediment transport. Downstream of these structures flow velocities increase due to constriction of the channel. Bed protection is often constructed in order to decrease the maximum scour hole and to shift the scour holes that involve a potential risk to structural stability to a greater distance from the hydraulic structure. Both hydraulic and geotechnical characteristics influence these two design parameters and are treated in more detail in subsequent sub-sections. Attention is paid to the processes relevant to sedimentation and consolidation, because these affect the erosion behavior of beds with cohesive sediments. The scour which may occur near a structure can be considered to be a result of bed scour caused by different processes. Owing to shear failures or flow slides, the scour process may progressively damage the bed protection. This will lead to the failure of hydraulic structures. The paper also discussed the effects of the angle of wave attack on coastal areas formation and the effect of wave attack angle variation on the sediment transport rates.

**Keywords:** *sediment trans-port, decrease the scour hole, erosion behavior of beds*

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## 1. Introduction

Hydraulic structures cause disturbances in uniform flow and sediment transport. Downstream of these structures flow velocities increase due to constriction of the channel. When the flow velocities decrease (i.e., in the deceleration zone), a higher degree of turbulence is generated and therefore a stronger erosion capacity is present.

In most cases this leads to scouring and, depending on the specific hydraulic conditions, there are sometimes steep upstream slopes. Bed protection is often constructed in order to decrease the maximum scour hole and to shift the scour holes that involve a potential risk to structural stability to a greater distance from the hydraulic structure. The main dimensions of the scour hole can be characterized roughly from the maximum scour depth expected during the lifetime of the structure and by the upstream scour slope. Both hydraulic and geotechnical characteristics influence these two design parameters and are treated in more detail in subsequent sub-sections. To ensure the safety and long term functioning of hydraulic structures, it is necessary to consider information with respect to failure mechanisms, boundary conditions and design criteria.

Attention is paid to the processes relevant to sedimentation and consolidation, because these affect the erosion behavior of beds with cohesive sediments. The scour which may occur near a structure can be considered to be a result of bed scour caused by different processes. Usually various time phases occur during the process of bed scour. Initially the development of scour is very fast but eventually a state of equilibrium is reached. Owing to shear failures or flow slides, the scour process may progressively damage the bed protection. This will lead to the failure of hydraulic structures.

## 2. Soil Erosion around the Maritime

### 2.1. Design Process

In recent years, the need for reliable information on modeling of sediment exposed to wave and current actions has been increasing. This need arises partly from an increase in the construction of structures which have to be protected to meet the higher safety standards [1,2,3]. When designing the maritime structures, the following aspects must be considered:

Function of the structure: erosion as such is not the problem as long as the structure can fulfill its function.

Physical environment: the structure should offer the required degree of protection against hydraulic loading, with an acceptable risk level and, when possible, meet the requirements resulting from landscape, recreational and ecological viewpoints,

Construction method: the construction costs should be minimized to an acceptable level and legal restrictions must be adhered to. Operation and maintenance: it must be possible to manage and maintain the hydraulic structure.

Elaboration of these points depends on specific, local circumstances, increasing the type of terrain (lowland or highland) and its development (economic value), availability of equipment, and availability of labors and the compulsory materials.

## 2.2. Boundary Conditions

In order to design hydraulic structures, loading (hydraulic conditions) and strength (morphological and geotechnical conditions) the parameters have to be specified. The main parameters are flow characteristics (flow velocities, water levels, discharges) and turbulence intensities determined by the geometry of the hydraulic structure and bed roughness characterize the flow pattern in the vicinity of the hydraulic structure and thus provide a measure of the erosion in the scour hole just downstream of the hydraulic structure. On the other hand, the scour process is also determined by the composition of the bed material (sub-soil).

## 2.3. Hydraulic Conditions

The most simple flow pattern is generated by a steady, uniform flow. However, special conditions for the flow pattern can be distinguished, for example, an accelerated flow in a local constriction, a river bend with well developed bend flow, an unsteady flow due to flood waves or tidal movement or when the direction of the flow downstream of hydraulic structures is perpendicular or inclined to the flow direction of a receiving river or estuary. In some special cases, an ice cover can divert the flow to the part of the bed near the hydraulic structure, resulting in an additional increase of local scour [4,5,6].

## 2.4. Morphological Conditions

For convenience, the sediments forming the boundaries of a flow are subdivided into cohesive and non-cohesive sediments, although there is a fairly broad transition range. In case of non-cohesive sediments such as sands and gravels, the particle or grain size and material density are the dominant material parameters for sediment transport. Bed material which is widely graded will be more resistant to scour than uniform material of the same median grain size ( $D_{50}$ ). During a flood, the finer grains of a non-uniform bed material are eroded in preference to the coarser grains, and so the median grain size of the bed material will increase. This process is known as armoring. The shape of grains, the surface packing of grains and multiple layers of different bed materials are considered as additional properties of the scour process.

The physio-chemical properties of cohesive sediments play a significant role in the resistance of cohesive

sediments against currents and waves effects. These properties depend strongly on granulometric, mineralogical and chemical characteristics of the sediment involved [7,8,9,10].

## 2.5. Geotechnical Conditions

A purely hydraulic and morphological approach to a given geometry (structure, bed protection) and hydraulic boundary conditions leads to scouring in which the maximum scour depth gradually increases and the upstream scour slope steepness (at least the steep part will become longer) until it reaches the equilibrium phase. This more or less continuous process may suddenly be disturbed by the occurrence of geotechnical instabilities along the upstream scour slope. In the extreme cases, these instabilities involve large masses of sediment and cause a major change of the shape of the upstream side of the scour hole in a relatively short period of time. The steeper this slope, the greater the probability of slope failure. Although it can be considered with a minor importance, the maximum scour depth also plays a role in that.

Beside these geotechnical aspects, the soil properties are extremely important, especially with regard to the type of geotechnical instability that may occur. Two types of instability are distinguished for cohesion less sediment, namely shear failure and flow slide. To predict the occurrence of a shear failure, the steepness of the upstream slope has to be assessed in relation to the angle of internal friction of the bed material  $\Phi$ . A flow slide is a more complex geotechnical phenomenon which can only occur in loose to very loose sand. However, the final geometrical characteristics of the upstream slope are generally of much greater importance in relation to flow slide instability than they are for a shear failure.

## 2.6. Fault Tree Analysis

The design process is characterized by solving design problems in an iterative manner. Since the processes involved are dynamic, it is impossible to reach the optimum solution at the first attempt. Though the optimum solution will never be attained, the design philosophy which has been adopted helps to prevent a haphazard approach for both design and research purposes. To produce a safe and reliable design, the total reliability as a function of all failure modes should be approximated, at least to be at a conceptual level. The fault tree is considered as a useful tool for integrating the various failure mechanisms into a single approach. The bed protection has to prevent or slow down a change in the geometry of the foundation.

A failure of the bed protection does not directly imply the loss of the structure, however, when the subsoil becomes unstable owing to the existence of a well-developed scour hole, the resistance of the foundation is reduced. A further advantage of the fault tree analysis is that this makes it possible to incorporate the failure of mechanical or electrical components as well as human errors in the management and maintenance of the structure. For instance, the safety of a sluice can be dramatically improved by regular echo-sounding of the bed protection and by subsequent maintenance if the initiation of a scour hole is discovered. The probability of instabilities

affecting the foundation is thus reduced to the coincidence of scour hole formation and failing in inspection and

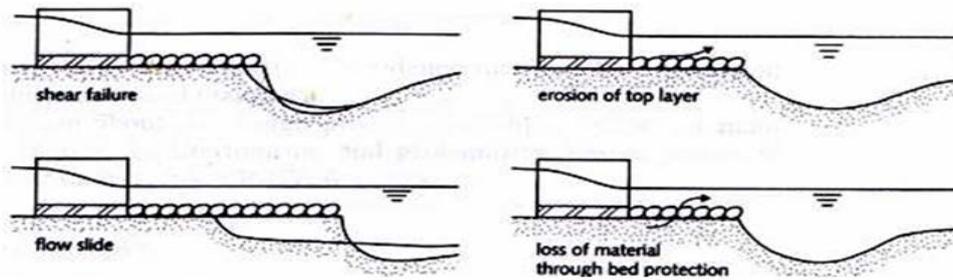


Figure 1. The common failure modes of an open bed protection [15,16]

## 2.7. Protective Measures

Several methods may be used to protect hydraulic structures from damage due to scouring. A conservative measure is to place the foundations of structures at such a depth that the deepest scour hole will not threaten the stability of the structure. Another way is to prevent the generation of erosive vortices. Hydraulic structures placed in waterways are often streamlined in order to reduce the drag exerted by flow and to reduce the effects of wake and turbulence intensity. Streamlining by means of deflectors and guide vanes, however, is effective only when the hydraulic structure is aligned with the flow within narrow limits.

Placing a bed protection downstream or around hydraulic structures is a common method of local scour protection. In principle, two types can be distinguished: the permeable, which is sand-tight and the impermeable. Scour occurs in the area of the bed beyond the flexible bed protection and, as the scour hole is formed, the bed protection slides down into it. When rock mattresses or loose riprap are used, consideration has to be given to the possibility of erosion of fines from underneath the bed protection. Local scour can be reduced or prevented by either reducing the loading parameters or by increasing the strength parameters [17,18,19].

## 2.8. Characteristics of Bed Protection Materials

From a geotechnical point of view, the stability of the upstream scour slope is of prime importance both during the scour process and in the final situation when the equilibrium geometry has been attained. Beside sediment transport in the scour hole, soil particles in the filter structure below the bed protection can also be transported in both vertical and horizontal directions. If the groundwater seepage flow becomes concentrated in narrow passages or pipes, the hydraulic structure may fail due to the transport of soil particles within the filter structure, so special attention must be paid to the sand percolation. Furthermore, the stability of both the upper layer and the end of the bed protection against current, waves and eddies has to be safeguarded. Thus, the bed protection and so the hydraulic structure will not be undermined [20,21,22].

## 3. Initiation of Motion in Sediment Transport-Mechanisms and their Caused Erosion

### 3.1. Initiation of Sediments Motion

maintenance. Figure 1 presents the common failure modes of an open bed protection [11,12,13,14].

The first treatise on initial bed grain instability using the concepts of Prandtl and von Kármán on boundary layer flow mentioned in the bibliography. When the flow velocity over a bed of non-cohesive material has increased sufficiently, individual grains begin to move in an intermittent and random fashion. Bed instability results from the interaction between two stochastic variables. At first, every grain on the bed surface can be assumed to be potentially susceptible to an instantaneous critical bed shear-stress. The grain becomes unstable if the instantaneous bed shear stress exceeds the critical one. Due to the random shape, weight and placement of the individual grains, these critical shear stresses will have a probability distribution. The other random variable is the instantaneous bed shear stress generated by the flow. The probability that the instantaneous bed shear stress is greater than a characteristic critical shear stress is a measure of the transport of sediment.

The physio-chemical properties of cohesive sediments play a significant role in the resistance of cohesive sediments to currents and waves. These properties depend strongly on the granulometric, mineralogical and chemical characteristics of the sediment involved. Up to now, direct quantitative relations between the physiochemical properties and the erosion rate have not been established. Nevertheless, design engineers require information to predict scour in cohesive sediments, because these soils are widespread natural sedimentary deposits.

### 3.2. Non-cohesive Sediments

The experimental data used by Shields was mainly obtained by extrapolating curves of sediment transport versus applied shear stress to the zero transport condition. Originally the data points were plotted by Shields and the curve (averaged critical value), constituting the 'Shields diagram, as usually quoted, was drawn by Rouse [23,24].

According to van Rijn [20], it seems justifiable to conclude that the Shields curve can also be applied as a criterion for the initiation of motion for oscillatory flow over a plane bed. Usually, small scale ripples are present and in such cases the critical velocities for initiation of motion are considerably smaller owing to the generation of vortex motions near the bed.

### 3.3. Cohesive Sediments

The initiation of motion and the transport of non-cohesive sediments are both determined by the submerged weight of the particles. For cohesive sediments, relatively large forces are necessary to break the aggregates within the bed and relatively small forces are necessary to

transport the material. Experiments by Mirtskhoulava [25,26] have shown that the scour of clay soils with a natural structure in a water saturated state occurs in several stages. In the initial stage loosened particles and aggregates separate and those with weakened bonds, are washed away. This process leads to the development of a rougher surface. Higher pulsating drag and lift forces increase the vibration and dynamic action on the protruding aggregates. As a result the bonds between aggregates are gradually destroyed until the aggregate is instantaneously torn out of the surface and carried away by the flow.

The above mentioned scour process is influenced by the following parameters: cohesion, action exchange capacity (CEC), salinity, Sodium Adsorption Ratio (SAR), pH-level of pore water, temperature, sand, organic content and porosity. The erosion rate of a cohesive bed is determined by the mutual effects of the sediment and pore water properties. A parameter describing the properties is the SAR, which is indicative of the processes in the diffusive double layer. In general, the critical bed shear-stress will increase with decreasing SAR and the critical bed shear-stress will increase when salt is added to the pore water. An increase in pH-level of the pore water and in temperature will decrease the strength of the bed.

An increase in CEC with low SAR will also result in an increase in cohesion: the critical bed shear-stress will increase and the erosion rate will decrease with increasing CEC. In general, an increase in organic content will cause an increase in the cohesiveness of the sediments, resulting in a larger critical bed shear-stress and a smaller erosion rate. However, this effect is known only qualitatively, and no quantitative information is found in the literature. The effect of sand on the strength a cohesive bed seems to be dependent upon the value of the SAR: at low SAR the strength of the bed will decrease with increasing sand content and at high SAR the reverse trend is expected. This effect also is known only qualitatively, and no quantitative information is found. In general, no applicable design equations for the depth of scour holes are available for cohesive sediments. In the literature most equations are related to one or two particular parameters influencing the erosion of cohesive sediments, moreover, they are often related to specific sediment.

The cohesion at saturation water content and the size of the particle diameter appear to be the most significant features among the extensive complex of physio-mechanical and chemical properties of cohesive sediments. However, it does not suffice to rely on averaged properties; the in homogeneity of the bed must also be considered. The erosion characteristics of cohesive sediments are not yet fully understood. For specific sediments at a given location, quantitative information relating to the erosion parameters is available but, for most situations the designer has to perform an erosion test [25,26,27,28].

### 3.4. Turbulence

For uniform flow the ratio between the bed turbulence and the bed shear-stress is approximately constant. Whereas for non-uniform two-dimensional flow the bed turbulence is strongly influenced by turbulence energy generated in the mixing layer, while for a three-dimensional flow the bed turbulence and the bed shear-stress is influenced by a combination of vortices with both

a horizontal and vertical axis. In a two-dimensional scour hole the bed turbulence can be represented combination of the turbulence energy generated at the bed and the turbulence energy from the mixing layer.

Under non-uniform flow conditions, there is no clear relation between the instantaneous sediment transport and the instantaneous bed shear-stress. Near-bed measurements of turbulent correlations are estimates of momentum flux, but are only related to the force acting on the bed when it is averaged over a long period of time. The relation between instantaneous products of velocity components and the instantaneous force on a sediment particle is not fully understood but even so, some general premises have been used to model the two important design parameters of the scour process; maximum scour depth and upstream scour slope. According to Breusers, the sediment transport in a scour hole is related to the difference between a maximum and a critical velocity raised to a power. The maximum velocity is a function of the local (or mean) velocity and the relative turbulence intensity at the end of the bed protection. Downstream of a sill the relative turbulence intensity depends strongly on the height of the sill (relative to the flow depth), the distance from the sill and the roughness of the bed [29,30].

### 3.5. Scour Processes

Hydraulic structures that obstruct the flow pattern in the vicinity of the structure may cause localized erosion or scour. Changes in flow characteristics of velocities or turbulence lead to changes in sediment transport capacity and hence to a local disequilibrium between actual sediment transport and the capacity of the flow to transport sediment. A new equilibrium may eventually be reached as hydraulic conditions are adjusted through scour. Scour which may occur at a structure can be divided into general scour and local scour. These possible processes have different length and time scales. As a first approximation, the scour caused by each process separately may be added linearly to obtain the resulting scour. In addition, scour in different conditions of sediment transport can be distinguished. In general, the time scale of local scour is relatively short. The time-dependent scour process in prototype situations however may be significant USACE [17].

### 3.6. Bend Scour

In general, bend scour depends on local parameters (bend curvature, flow depth, grain size) and upstream influences (redistribution of flow and sediment transport). In the outer part of bends excess scour occurs as the result of spiral flow. The excess bed scour is due to this spiral flow and an overshoot phenomenon. The bed adjusts to changing conditions by a damped response, overshooting the fully developed solution. The magnitude of this overshoot depends strongly on the width to depth ratio and the overshoot grows with increasing ratio. Due to this overshoot effect, it is difficult to formulate a simple predictor for the bend scour although such a predictor is often needed to provide a first estimate of the scour. Figure 2 shows the expected scour in bends.

### 3.7. Local Scour

Local scour results directly from the impact of the structure on the flow. Physical model testing and prototype experience have permitted the development of methods for predicting and preventing scour at different types of structures. Information with respect to scour can be obtained by testing physical models and this approach may be particularly appropriate for unusual structures not covered by existing formulae or for field measurements of scour at existing structures. The accuracy of the scour computation mainly depends on the accuracy of the measurements of flow velocities and the turbulence intensities. The development of the scour process depends on the flow velocity and turbulence intensity at the transition between the fixed and the eroded bed. By applying this concept, the scour prediction can be restricted to one computation; no information is needed concerning the near bed velocities and bed turbulence in the scour hole.

When dealing with local scour problems, only the maximum scour depth in the equilibrium phase is relevant. This is especially true for isolated structures such as bridge piers, abutments and other permanent structures (sills, weirs, final closure works). However, there are cases in which the time factor is important particularly, for example, in the case of closure of estuary branches. Understanding of the physical condition and mathematical modeling of water and sediment movement in rivers, estuaries and coastal waters has made much progress in recent years. but this progress has also raised many new research questions [28,29,30].

### 3.8. Conditions of Transport

Clear-water scour occurs when no upstream sediment is present, that is when the bed material in the natural flow upstream of the scour hole is at rest or when the bed upstream of the scour hole is fixed. If the scour is caused by flow that is not transporting sediment (bed load and suspended load), the depth of scour should approach a limit asymptotically. When the approach velocity is greater than the critical mean flow velocity, the upstream bed is usually covered to prevent the approaching flow from moving the bed particles. Live-bed scour is scour with sediment transport over the upstream undisturbed bed. Sediment particles which are continuously transported by the flow enter the scour hole. In such cases, the equilibrium scour depth is smaller than that in clear-water scour conditions. In general, for the live-bed case, the scour increases rapidly with time and then fluctuates about a mean value in response to the bed features which are being passed. The maximum scour depends on the variation in the depth of flow.

Based on clear-water scour experiments using scale models with small Froude numbers [29,30] distinguished four phases in the evolution of a scour hole as presented in Figure 3: an initial phase, a development phase, a stabilization phase and an equilibrium phase. In the initial phase, the flow in the scour hole is nearly uniform in the longitudinal direction. This phase of the scour process can be characterized as the phase in which the erosion capacity is most severe. Observations with fine sediments showed that at the beginning of the scour hole development some bed material near the upstream scour slope goes into suspension. Most of the suspended particles follow convectional paths within the main flow

and remain in suspension due to the internal balance between the upward diffusive flux and the downward flux due to gravity. Some of the particles will settle and will be re-suspended owing to the large bursts of the turbulent flow near the bed, while some particles with a jump height smaller than a defined reference height are transported as bed load.

During the development phase the scour depth increases considerably, but the shape of the scour hole does not change. In this phase the ratio between the maximum scour depth and the distance from the end of the bed protection to the point where the scour hole is at its maximum is more or less constant. The suspended load close to the bed has decreased significantly compared to the condition in the initial phase. This can mainly be ascribed to the decrease in the flow velocities near the bed over time, despite the increase of the turbulence energy. Though bed particles are picked up and carried by the flow, the time-averaged value of the sediment transport in the upper part of the upstream scour slope is negligibly. Science the contribution of the sediment transport due to the instantaneous velocities in the downstream direction is approximately equal to the transport resulting from the instantaneous velocities in the upstream direction [29,30].

In the stabilization phase the rate of development of the maximum scour depth decreases. The erosion capacity in the deepest part of the scour hole is very small compared to the erosion capacity downstream of the point of reattachment, so that the dimensions of the scour hole increase more in the longitudinal direction than in the vertical direction. Figure 3 presents the scour hole development process behind the bed protection. The more the scour process continues, the more the flow velocities above the lower part of the upstream scour slope decrease. In the stabilization phase the equilibrium situation for both the upstream scour slope and the maximum scour depth is almost achieved. The equilibrium phase can be defined as the phase in which the dimensions of the scour hole do no longer change significantly [6,9].

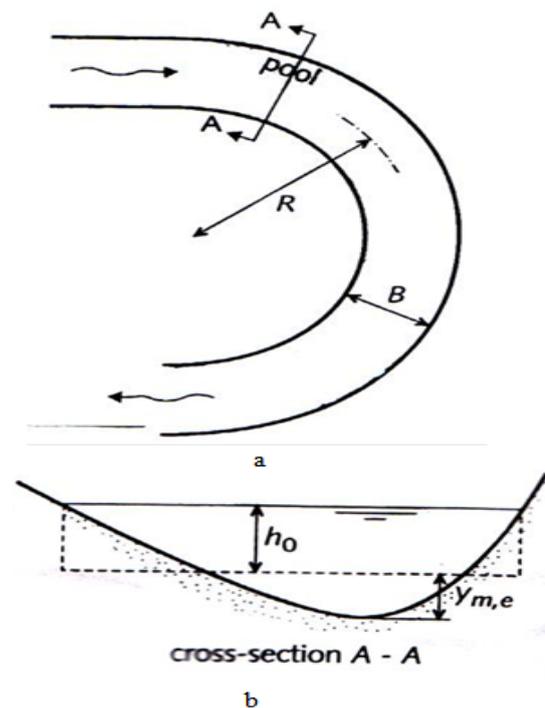


Figure 2. Expected scour in bends [25]. (a) Bend with an expected scour and (b) cross section in the bend

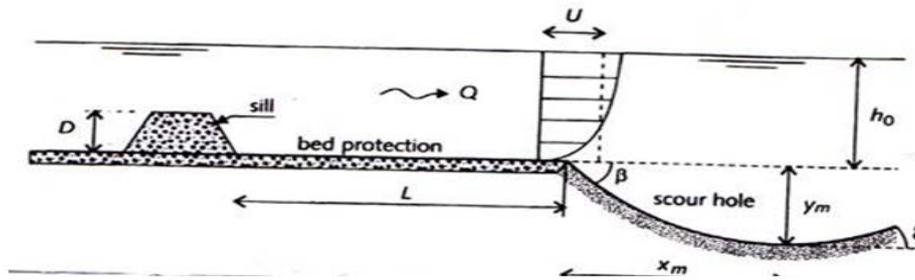


Figure 3. Scour hole development process behind the bed protection [25]

#### 4. Effects of the Angle of Wave Attack on Coastal Areas Formation

The variation of the angle between the wave crests and shoreline segment ( $\Phi_o$ ) has a big effect in such formation based on its effect on the sediment transport rate ( $S_x$ ). In some cases, additional constant drift ( $S_o$ ) to be added. Details is as presented in Figure 4, which presents a neat sketch for the effects of the wave angle attack on the lognshore sediment transport gradient variation.

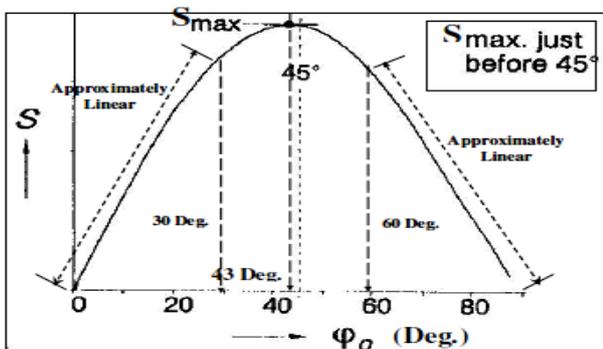


Figure 4. Wave attack angle ( $\Phi_o$ ) variation

In order to investigate the effect of changes in ( $\Phi_o$ ) on ( $S_x$ ), the depend parameters upon ( $\Phi_o$ ) should be determined. Obviously,  $\sin(\Phi_o)$  and  $\cos(\Phi_o)$  and ( $C_b$ ) affect also, science the wave height at the edge of the breaker zone depends upon the refraction coefficient. This variation in wave height implies that the outer edge of the breaker zone shifts as ( $\Phi_o$ ) changes. This is supported by the fact that ( $C_b$ ) is directly dependent on ( $h_b$ ). The function of  $F(\Phi_o)$  can be simply represented based on its main parameters, as given in relation:  $F(\Phi_o) \& [C_b, \sin(\Phi_o), \cos(\Phi_o)]$  [10,11].

Here:

- $F(\Phi_o)$  = wave attack angle ( $\Phi_o$ ) function.
- ( $\Phi_o$ ) = angle between the wave crests and shoreline segment (Deg.).
- $C_b$  = wave celerity,  $u_o$  = current velocity to cause the steering action of sediments in the bottom, (m/s).

Unfortunately, this function can not be expressed in a simple algebraic form. Rather than presenting the numerical procedure for evaluating the relation, the results of such a study found by evaluating the function for a whole series of values of ( $\Phi_o$ ) to be discussed. The factors  $\sin(\Phi_o)$  and  $\cos(\Phi_o)$  are the most important in the function. In contrast to  $\sin(\Phi_o)$  and  $\cos(\Phi_o)$ , which is symmetrical about the line ( $\Phi_o = 45^\circ$ ), the function  $F(\Phi_o)$  is mathematically asymmetric, values of  $F(\Phi_o)$  for ( $0 < \Phi_o < 40^\circ$ ) are generally higher than corresponding values of  $F(90-\Phi_o)$ . The peak value of  $F(\Phi_o)$  occurs for ( $\Phi_o < 45^\circ$ ),

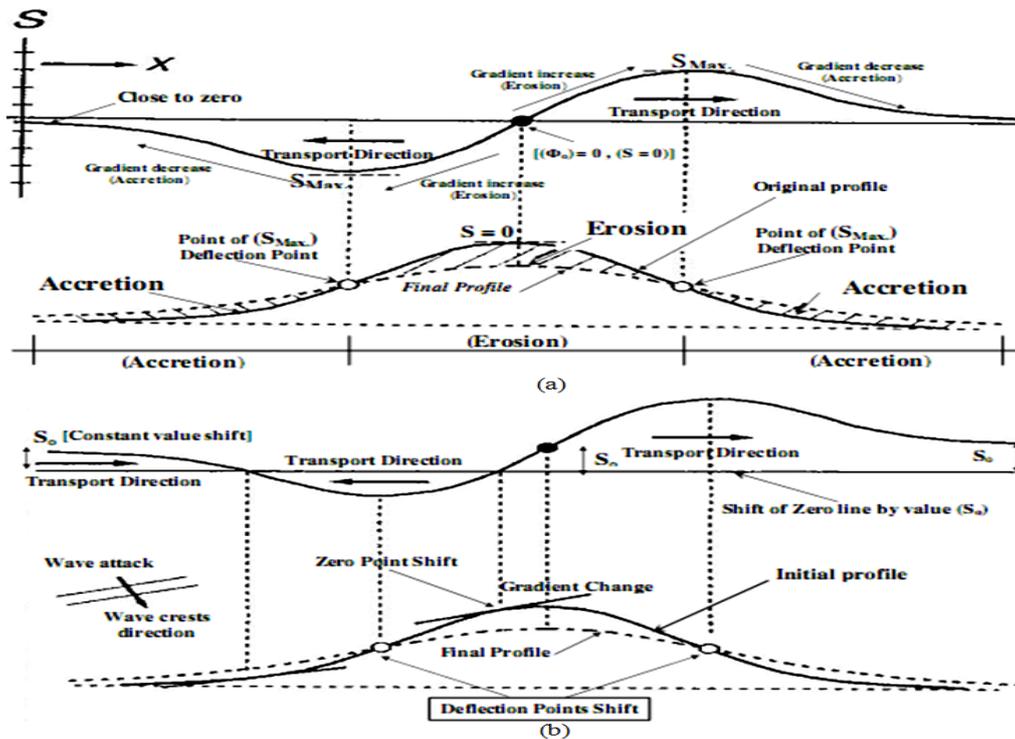
usually somewhere (between  $40^\circ$  and  $45^\circ$ , approximately equals  $43^\circ$ ), see Figure (Figure 5a).

As it is well established, the driving force for the longshore current within the breaker zone is provided by the radiation stress, which can be expressed. Outside the breaker zone, the radiation stress ( $S_{yx}$ ) for any point outside the breaker zone is considered constant. The following points summaries the relationships among ( $S$ ), ( $\Phi_o$ ) and wave attack intensity (severances). Theoretical case (wave crests are parallel to the shore line), or perpendicular on it (case:  $\Phi_o = 0^\circ$  &  $S = 0$ ) and (case :  $\Phi_o = 90^\circ$  &  $S = 0$ ). Based on the results, the relation between ( $\Phi_o$  &  $S$ ) can be considered linear for small values of the angle ( $\Phi_o$ ). Maximum transport rate ( $S_{Max}$ ) comes with an angle close to  $45^\circ$  ( $\Phi_o = 43^\circ$ ). The ( $S$ ,  $\Phi_o$ ) relation distribution is not exactly symmetric and very close in shape to the mathematical Sin curve. Figure 5a presents the sediment transport without additional constant littoral drift, ( $S_o$ ). Figure 5b presents the sediment transport without additional constant littoral drift, ( $S_o$ ). Figure 5: The effects of the wave attack angle ( $\Phi_o$ ) on the lognshore Sediment transport gradient variation ( $S_x$ ).

At small values for the wave attack angle ( $\Phi_o$ ), the longshore sediment transport is considered small. It can be considered just able to steer up the sediments without causing their movement due to the existence of weak velocity of currents. Erosion and accretion processes occur based on the sediment transport gradient variation. The upward gradient in the representative function means causing erosion and downward one means causing accretion [10,11].

#### 5. Effect of Wave Attack Angle Variation On the Sediment Transport Rates

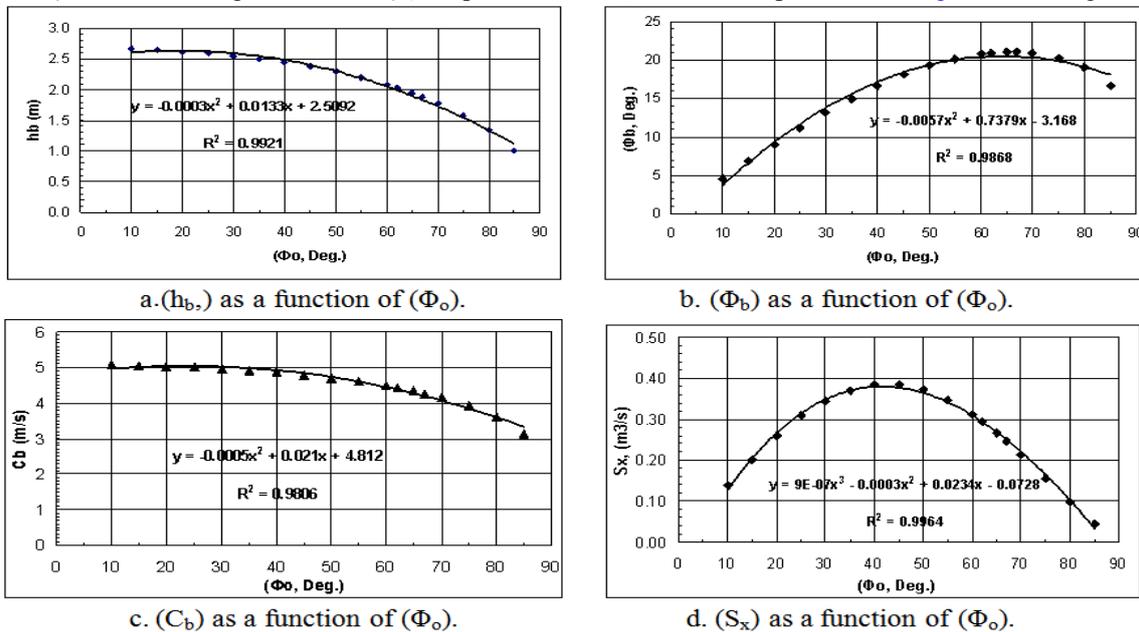
The study deals with the case of the transformed waves in winter season. Based on the transformed waves in winter season, a value of significant wave height equals ( $H_{sbr} = 2m$ ) was applied as a representative value for the breaking process in this area. The carried out evaluation applied the following values into consideration: [Initial wave height in the breaking area  $H_{sbr} = 2m$ ,  $T_m = 7s$ ,  $\gamma = 0.7$ ]. The applied evaluation procedure is considered simple in application. By choosing values for the angle ( $\Phi_o$ ), the ones at the breaker line ( $\Phi_b$ ) can be calculated (choose  $h_b$ , calculate ( $H_b$ ) check ( $H_b / h_b < \text{or} > \gamma = 0.7$ ), after you choose new ( $h_b$ ), repeat the and process again and so on. The evaluation results for various values of ( $\Phi_o = 0$  to  $90^\circ$  theoretically and " $10^\circ$  to  $85^\circ$ " practically to occur as a realistic wave attack angle) against ( $h_b$ , m), ( $\Phi_b$ , Deg.), ( $C_b$ , m/s) and ( $S_x$ ,  $m^3/s$ ) are as presented in Figure 6.a through 6.d.



**Figure 5.** The effects of the wave attack angle ( $\Phi_0$ ) on the longshore sediment transport gradient variation ( $S_x$ ). (a) Sediment transport without additional constant littoral drift, ( $S_0$ ) and (b) Sediment transport with additional constant littoral drift, ( $S_0$ )

Simple application is considered for the applied evaluation procedure. By choosing reasonable values for the angle ( $\Phi_0$ ), then the angles at the breaker line ( $\Phi_b$ ) can be calculated (choose  $h_b$ , calculate ( $H_b$ ) check ( $H_b / h_b < \text{or} > \gamma = 0.7$ ). After choosing a value for ( $h_b$ ), repeat the

process again and so on. The evaluation results for various values of ( $\Phi_0 = 0^\circ$  to  $90^\circ$  theoretically and " $10^\circ$  to  $85^\circ$ " practically to occur as a realistic wave attack angle) against ( $h_b$ , m), ( $\Phi_b$ , Deg.). The parameters ( $C_b$ , m/s) and ( $S_x$ ,  $m^3/s$ ) are as presented in Figure 6.a through 6.d.



**Figure 6.** Different sediment transport parameters As a function of  $\Phi_0$ . (a)  $h_b$ , (b)  $\Phi_b$ , (c)  $C_b$  and  $S_x$  as a function of  $\Phi_0$

## 6. Conclusions

- At the breaker line with increasing the value of offshore wave attack angle ( $\Phi_0$ , practical values between  $10^\circ$  and  $85^\circ$ ), both the wave celerity ( $C_b$ , "m/s") and water depth at breaker line ( $h_b$ , "m") decrease with an inverse correlation till a practical value equals ( $\Phi_0 = 85^\circ$ ).

- In a direct correlation, the value of wave attack angle at the breaker line ( $\Phi_b$ ) increase with increasing the values of ( $\Phi_0$ ), to a certain value of ( $\Phi_0 = 65^\circ$ ) approximately. After, the correlation becomes inverse between ( $\Phi_0$ ) and ( $\Phi_b$ ) till a practical value equals ( $\Phi_0 = 85^\circ$ ).
- Strong correlations are already existed among all the parameters affect the wave attack angle on the sediments transport rates.

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