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Review of Wave Transformation and Cross-Shore Sediment Transport Processes in Surf Zones

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ABSTRACT

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An attempt is made to assemble and synthesize recent publications which may contribute to the improvement of our quantitative capabilities for predicting shoreline changes due to the cross-shore sediment transport in the surf and swash zones on beaches. This review is essentially limited to the cross-shore hydrodynamics of incident wind waves and surf beat motions as well as the cross-shore sediment transport and resulting beach profile evolution.

ADDITIONAL INDEX WORDS: *Wave breaking, surf, swash, sediment transport, erosion, beaches.*

INTRODUCTION

Geologists, engineers and oceanographers have been investigating coastal erosion problems. Three-dimensional morphologic changes of beaches in response to incident wave energy were described qualitatively by SHORT (1978) and WRIGHT *et al.* (1978). The beach conditions examined in these descriptive studies ranged from reflective systems in which much of the incident wave energy is reflected from the steep beach face to dissipative systems with wide surf zones and dissipation of incident wind wave energy. Practical coastal engineering problems associated with littoral processes are discussed in the Shore Protection Manual (U.S. ARMY CERC, 1984), which also gives design procedures heavily based on site specific data. At present, the only way to estimate long-term shoreline erosion or accretion appears to be through an analysis of available field data, although continuing efforts have been made by a large number of researchers to improve our quantitative understanding of nearshore hydrodynamics and sediment transport mechanics. For example, MAY *et al.* (1983) assembled data on the rate of shoreline change for 1,689 sites in the United States. The data were acquired by a variety of methods ranging from precise engineering surveys to general appraisals of old photographs.

Considering the complexity and diversity of the littoral processes, the following brief review is essentially limited to cross-shore hydrodynamics and sediment transport mechanics inside the breaker line where waves breaking on a beach cause a superelevation of the mean water level (setup), generate turbulence and enhance sediment entrainment. The state-of-the-art of sediment transport mechanics mostly outside the breaker line was reviewed by SLEATH (1984), while the present understanding of the bottom boundary layer over the continental shelf was summarized by GRANT and MADSEN (1986). A very recent review of the surf zone dynamics by BATTJES (1988) includes longshore hydrodynamics and nearshore circulations. Existing models and data on longshore sediment transport were discussed by BODGE (1987).

First, empirical models for predicting beach and dune erosion by a storm are reviewed. These simple models are easy to apply and could eventually be extended to simulate long-term shoreline erosion or accretion if the recovery processes of the eroded beach and dune following the storm could be quantified. Since a quantitative understanding of wave and current

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actions causing the cross-shore sediment transport is essential, a review is given of recent studies on the transformation of incident wind waves in the surf and swash zones. In addition, recent field observations and theories concerning low-frequency (surf beat) motions are summarized since they may become dominant near the shoreline on gently sloping dissipative beaches. The cross-shore sediment transport processes are then discussed in light of the improved understanding of the cross-shore hydrodynamic processes. It should be mentioned that an attempt is made to cite recent references only to make this review reasonably concise.

BEACH AND DUNE EROSION

DEAN (1983) reviewed practically-oriented methods for predicting shoreline erosion caused by offshore sediment transport during an extreme storm. These methods are based on the concept of equilibrium beach profiles which are representative of observed beach profiles (BRUUN, 1954; DEAN, 1977). An initial beach profile is assumed to adjust itself to the specified equilibrium profile for given storm surge, incident wave height and sediment characteristics. Regarding storm surge as sea level rise of short duration, these methods are basically modifications of the Bruun rule of shoreline erosion due to gradual sea level rise (BRUUN, 1983). VELLINGA (1983, 1986) showed usefulness of such an empirical model for predicting the severity of beach and dune erosion in the Netherlands although it was required to calibrate and verify the model using site-specific field data and extensive laboratory data. Similitude requirements for small-scale laboratory experiments on beach profile evolution were investigated by a number of researchers (*e.g.* KRIEBEL *et al.*, 1986; VELLINGA, 1986).

Since the duration of a storm may be short relative to the time required for the beach profile adjustment, KRIEBEL and DEAN (1985) developed a numerical model for predicting the temporal change of the beach and dune profile during a storm. The model employs the equation of sediment continuity and an empirical formula for the offshore sediment transport rate expressed in terms of the actual and equilibrium levels of wave energy dissipation in the surf zone. KRIEBEL and DEAN (1984) also applied their model to estimate the probability distribution of dune recession due to hurricanes using a Monte Carlo simulation method. KOBAYASHI (1987) supplemented their work and showed that the problem of beach and dune erosion by a storm could be formulated as a one-dimensional diffusion problem with moving boundaries at the breaker line and shoreline. However, these analyses also revealed difficulties in developing a general formula for the cross-shore (offshore and onshore) sediment transport and specifying appropriate boundary conditions without the knowledge of the hydrodynamics and sediment transport mechanics in the cross-shore direction. Some recent studies directed toward the improvement in this knowledge are reviewed in the following. At present, no satisfactory model is available to predict the recovery of the eroded beach and dune due to onshore sediment transport after a storm. Such a model is essential for simulating long-term shoreline erosion or accretion.

INCIDENT WAVE TRANSFORMATION

FREILICH and GUZA (1984) and ELGAR and GUZA (1985a, 1985b, 1986) investigated the nonlinear evolution of non-breaking random waves shoaling on a sloping bottom in relatively shallow water. A nonlinear model based on the Boussinesq equations for a sloping bottom (PEREGRINE, 1967) was developed to describe the evolution of the wave field's Fourier amplitudes and phases. The nonlinear model was shown to be generally superior to linear finite-depth theory for the prediction of the detailed evolution of the observed wave fields. Use of such a nonlinear model for shoaling random waves may eventually be necessary to evaluate the effects of wave nonlinearity and randomness on the cross-shore sediment transport outside the breaker line which needs to be considered to better quantify the sediment flux across the breaker line.

Waves advancing onto a beach generally break before arriving at the shoreline. PEREGRINE (1983) reviewed the fluid dynamics of wave breaking. The idealization of inviscid, initially irrotational flow has been proved to be sufficiently successful in predicting when and how waves break. For beaches of gentle slope, most breaking waves have been found to settle into the quasi-steady state in which the wave form changes relatively slowly and has a strongly turbulent region on the face of the wave, called a surface roller. Experimental efforts are also being made to measure the detailed velocity field of breaking or broken waves in the surf zone using sophisticated instruments such as laser Doppler anemometers (*e.g.* STIVE, 1980; STIVE and WIND, 1982; BATTJES, 1988). SVENDSEN (1987b) analyzed available laboratory data on turbulent kinetic energy in the surf zone to elucidate the spatial and temporal variations of the turbulence properties of surf zone waves.

A number of researchers have attempted to predict the variations of the wave height and setup across the surf zone on a gentle slope using the time-averaged equations of energy and momentum. SVENDSEN (1984a) proposed a realistic theoretical model for monochromatic waves which accounted for the effect of the actual shape of the quasi-steady breaking wave with the surface roller on the basis of experimental data. The model was shown to yield good agreement with laboratory data except for the wave set-down (negative setup) in the transition region landward of the point of wave breaking where the assumption of the quasi-steady breaking wave may not be valid. The same difficulty was encountered by STIVE and WIND (1982) who compared conventional models based on potential wave theories with their wave setup data. EBERSOLE (1987) showed that the model of SVENDSEN (1984a) gave reasonable agreement with his field measurements of the wave height decay of individual waves which were essentially treated as monochromatic waves. On the other hand, BATTJES and STIVE (1985) calibrated and verified the model proposed by BATTJES and JANSSEN (1978) for predicting the variations of the root-mean-square wave height and setup of random breaking waves across the surf zone in which the breaking of random waves was modeled in a semi-empirical manner. The calibrated model was shown to be in agreement with an extensive set of laboratory and field data except that the predicted interval of steepest rise of the mean water level was systematically too far seaward. As a result, it is required to improve our capabilities of predicting the wave setup for both monochromatic and random waves.

Considerable efforts have recently been made to predict and measure the undertow which is the cross-shore bottom current flowing seaward from the shoreline to compensate the mass of water carried shoreward by the breaking waves in the surf zone (SVENDSEN, 1984b; HANSEN and SVENDSEN, 1984; DALLY and DEAN, 1986). The undertow is driven by the local difference between the radiation stress and the setup pressure gradient which only balance each other over the entire depth. The difference between these two forces is balanced by turbulent shear stresses due to the undertow current. SVENDSEN *et al.* (1987) combined the model for the undertow developed by SVENDSEN (1984b) with a boundary layer solution in order to satisfy the zero velocity boundary condition at the bottom. The combined model for the undertow and boundary layer flow was shown to be capable of reproducing measured current profiles below the wave trough accurately although the mean volume flux below the wave trough and the local force difference driving the undertow were specified as input using the measured velocity and setup values. In other words, the undertow could be predicted accurately if these quantities could be predicted accurately. Attempts are also made to predict the three-dimensional current system in the surf zone (*e.g.* STIVE and DE VRIEND, 1987).

In addition to the time-averaged quantities such as the undertow, setup and wave height, which may be obtained from the time-averaged equations for mass, momentum and energy, knowledge of the time-varying quantities such as the oscillatory velocities and swash oscillation is required for predicting the cross-shore sediment transport in the surf and swash zones on a beach. It may be noted that the time-varying location of the shoreline water level about the still water level is normally separated into a superelevation of the mean water level, called setup, and fluctuations about the mean level, called swash (*e.g.* GUZA and THORNTON, 1982; HOLMAN and SALLENGER, 1985). HIBBERD and PEREGRINE (1979) used an explicit dissipative finite difference method of the type suggested by Lax and Wendroff to solve the finite-amplitude, shallow-water equations in the time domain for a uniform bore on a beach of uniform slope. Numerical methods developed for flows with shocks were recently reviewed by MORETTI (1987). The numerical method of

HIBBERD and PEREGRINE (1979) is a shock-capturing method in which the shape of a wave front (shock) is frozen to cover a small number of computation points, and a separate treatment of the front is not required, unlike shock-fitting methods such as those based on characteristics. Their numerical solution was capable of describing the behavior of the bore runup and the formation of a landward-facing bore in the downrush. PACKWOOD (1980) included viscous effects and studied periodic and irregular bores on beaches. PACKWOOD (1983) examined the influence of a porous bed on the uprush and downrush of a single bore on a gentle sandy beach. SVENDSEN and MADSEN (1984) included the effects of turbulence generated by wave breaking to describe a turbulent bore on a beach without using numerical dissipation.

KOBAYASHI, OTTA and ROY (1987) modified the numerical model for beaches used by PACKWOOD (1980) to predict wave uprush and downrush on the rough steep slope of a coastal structure as well. The modified numerical model was shown to yield good agreement with available large-scale and small-scale test data on wave runup, rundown and reflection from uniform and composite riprap slopes. KOBAYASHI and GREENWALD (1986) conducted small-scale tests using a 1:3 gravel slope with an impermeable base to further calibrate and evaluate the numerical model. The calibrated numerical model was shown to be capable of predicting the measured temporal variations of the hydrodynamic quantities on the rough impermeable slope. Moreover, KOBAYASHI and WATSON (1987) showed that the numerical model could also be applied to smooth steep slopes by adjusting the friction factor associated with the bottom roughness. The numerical model of KOBAYASHI *et al.* may hence be applied to predict incident wave reflection and swash oscillations on relatively steep beaches. Incident swells were observed to be reflected almost completely from a steep beach face (SUHAYDA, 1974). This numerical model may also be applied to gently sloping beaches, although this suggestion needs to be verified. In any case, it is desirable to develop a single model which can predict both time-varying and time-averaged hydrodynamic quantities for a beach of arbitrary geometry and reflectance.

LOW FREQUENCY MOTIONS

The hydrodynamic problems reviewed above are limited to the period range of the incident waves which is generally less than 20 seconds. KOMAR and HOLMAN (1986) recently reviewed coastal erosion processes and emphasized the importance of infragravity (surf beat) motions in the period range greater than 20 seconds, particularly in the swash zone on a gentle slope. These low-frequency motions may be in the form of edge waves, which are trapped to the shoreline by wave refraction and may be progressive or standing in the alongshore direction, as well as untrapped leaky waves, which are standing in the cross-shore direction. The low-frequency motions may be important for shoreline erosion, but they are, at present, not predictable for given incident waves and beach geometry. The following review is essentially limited to untrapped standing waves in the cross-shore direction to be consistent with the rest of the review given in this paper. As for edge waves, subharmonic edge waves whose period is twice that of the incident waves may form on steep reflective beaches (*e.g.* GUZA and BOWEN, 1976), while the nonlinear interaction of the incident waves of slightly different periods and possibly different angles of incidence may result in low-frequency edge waves on gentle dissipative beaches (*e.g.* GALLAGHER, 1971; BOWEN and GUZA, 1978). Field observations of the infragravity wave velocity field in the surf zone on California beaches indicated the dominance of progressive low-mode edge waves for the longshore currents but the presence of other low-frequency motions such as high-mode edge and/or leaky waves for the cross-shore currents (HUNTLEY *et al.*, 1981; OLTMAN-SHAY and GUZA, 1987).

On the other hand, the low-frequency motions in the cross-shore direction may be caused by normally incident wave groups. GUZA and THORNTON (1985b) critically reviewed existing models and presented their field data which was qualitatively consistent with the standing wave models. LONGUET-HIGGINS and STEWART (1962) theoretically showed the existence of a forced low-frequency wave associated with incident wave groups such that there should be a depression of the mean water level under large waves and a corresponding rise in the mean water level under small waves. HUNTLEY and KIM (1984) observed that the low-frequency cross-shore velocities measured outside the surf zone were strongly correlated with the incident wave envelope, suggesting the dominance of the forced wave motion. GUZA and THORNTON (1985b) suggested that the reflection of the forced low-frequency wave near the shoreline should produce something like a standing wave, consistent with their observations.

SYMONDS *et al.* (1982) proposed a model for long wave generation by the temporal variations of the breaker line and wave setup by normally incident wave groups in which the effect of the forced low-frequency waves was not considered but could be superposed for their linear analysis. Their model predicts standing waves in the surf zone and an outgoing progressive wave outside the surf zone, although their analysis of wave setup may not be very accurate in light of the data and analysis presented by STIVE and WIND (1982). This model was extended by SYMONDS and BOWEN (1984) to include a linear shore parallel bar. The extended model indicates the possible occurrence of a half wave resonance having an antinode in the sea surface elevation and a node in the velocity at the bar crest, which might lead to convergence in suspended load at this point and hence to a possible mechanism of the bar maintenance. SALLENGER and HOLMAN (1987) made measurements of cross-shore flow across the surf zone during a storm as a nearshore bar became better developed and migrated offshore. The analyzed data for the first day of the storm indicated a dominant low-frequency wave having a node in the velocity reasonably close to the bar crest, consistent with the model of SYMONDS and BOWEN (1984). There was, however, no evidence of a dominant wave having a velocity node at the bar crest later during the storm when the bar had migrated farther offshore. The response of this bar surveyed periodically through the storm and the following recovery period was discussed in more detail by SALLENGER *et al.* (1985), who also reviewed existing models for bar formation. Different models appear to be required to explain the formation of nearshore bars under different conditions.

Low-frequency motions were observed to be important especially in the swash zone on gently sloping beaches (*e.g.* GUZA and THORNTON, 1985b). Measurements were made of the time-varying location of the shoreline water level on natural beaches using a time-lapse camera (HUNTLEY *et al.*, 1977; HOLMAN and SALLENGER, 1985) as well as a resistance wire gauge (GUZA and THORNTON, 1982). The measured shoreline oscillation was separated into the mean vertical elevation, setup, and the fluctuating component, swash. For monochromatic waves, the swash is dominant for steep slopes and incident waves of low steepness, while as the slope is reduced and the wave steepness is increased, the setup becomes more important since the incident wave energy is dissipated in the wise surf zone (*e.g.* BATTJES, 1974; GUZA *et al.*, 1984). Relatedly, reflection of incident monochromatic waves decreases as the swash is reduced in comparison with the setup. For swash oscillations on natural beaches, HUNTLEY *et al.* (1977) suggested that the swash consists of saturated high-frequency and unsaturated lower-frequency components corresponding roughly to the incident wave and low-frequency bands. The swash oscillations on a gently sloping beach were measured by GUZA and THORNTON (1982). The swash spectra at incident wave frequencies were independent of the incident wave height, suggesting saturation, whereas the significant swash excursion obtained from the low-frequency spectral region increased approximately linearly with the significant incident wave height. Extensive field observations of wave setup and swash on a moderately steep beach made by HOLMAN and SALLENGER (1985) indicated the dependence of the measured swash on the surf similarity parameter (BATTJES, 1974) which decreases as the foreshore slope is reduced and the incident wave steepness is increased. For small surf similarity parameters, the results were apparently consistent with those of GUZA and THORNTON (1982). For large surf similarity parameter, no signs of the saturation in the incident wave frequency band were seen. Possible reasons for this discrepancy were discussed by GUZA *et al.* (1984). HOLMAN (1986) extended the analysis of the dataset of HOLMAN and SALLENGER (1985) and presented extreme value statistics of the measured wave runup maxima, which may be more useful for coastal engineering applications.

Experimental studies were also made to reproduce low-frequency motions induced by normally incident wave groups in a wave tank. KOSTENSE (1984) generated two primary waves of nearly equal frequency and employed a sophisticated control of the wave paddle including second-order wave generation as well as active wave absorption at the paddle face in order to generate low-frequency waves limited to an incident forced wave and a reflected free wave generated in the surf zone. The measurements made outside the surf zone were in qualitative agreement with the outgoing progressive wave predicted by the model of SYMONDS *et al.* (1982). MANSARD and BARTHEL (1984) examined shoaling properties of forced low-frequency waves induced by random waves characterized by JONSWAP spectra. A porous beach with a 1:30 slope for dissipating wave energy was used instead of active wave absorption at the paddle face. Suppression of spurious low-frequency waves by controlling the paddle motion was recommended for a realistic reproduction of low-frequency motions in a wave tank. It should be mentioned that previous experiments on beach profile evolution were conducted with no or little regard to low-frequency motions and reflection at the wave paddle of waves reflected from beaches. Nevertheless, successful duplication of prototype events during highly erosive storm conditions was possible (*e.g.* VELLINGA, 1986), whereas simulation of post-storm recovery was found to be more difficult (KRIEBEL *et al.*, 1986). The present understanding of cross-shore sediment transport processes is not sufficient to quantify the effects which were not accounted for in these experiments. For highly erosive storm events, the effect of storm surge might be more important than the neglected effects. In any case, future experiments should attempt to reproduce incident wind waves and low-frequency motions as well as to eliminate wave reflection from the paddle face.

CROSS-SHORE SEDIMENT TRANSPORT

The analysis of sediment transport under the action of waves and currents is generally separated into bed load and suspended load since no general theory is yet available to describe all phases of sediment transport even under the action of currents alone (*e.g.* KOBAYASHI and SEO, 1985). Bed load models such as those proposed by MADSEN and GRANT (1976) and KOBAYASHI (1982) for non-breaking waves assume that bed load particles respond to the instantaneous bed shear stress and the local bed slope without any time and spatial lag. These models may also be applied for breaking or broken waves, but the instantaneous bed shear stress in the surf and swash zones is, at present, not well understood for lack of data. A diffusion equation is normally used to describe the instantaneous concentration of suspended sediment for non-breaking waves (*e.g.* GLENN and GRANT, 1987) and for breaking or broken waves (*e.g.* DEIGAARD *et al.*, 1986). The difficulties associated with use of the diffusion equation in the surf zone are modeling of the turbulent diffusion coefficient without sufficient knowledge of surf zone turbulence, as discussed by SVENDSEN (1987a), and specification of the bottom concentration of suspended sediment which is normally related to the instantaneous bed shear stress.

A simpler approach is to apply the model for total load (bed load plus suspended load) proposed by BAILARD (1981) on the basis of the Bagnold's energetics-based model for streams. The model expresses the transport rate of total load as a function of the instantaneous near-bottom water velocity and the local bed slope. Uncertainties of the model are the empirical coefficients included in the model and the definition of the near-bottom velocity. Moreover, suspended sediment particles far from the bed may not respond instantaneously to the near-bottom velocity and the local bed slope.

The models discussed above require knowledge of the time-varying flow characteristics to predict the instantaneous (time-varying) rate of sediment transport from which the net (time-averaged) rate of sediment transport can be computed. The flow characteristics over a moveable sediment bed can be significantly different from those over a rigid bed (GRANT and MADSEN, 1986). Wave-induced ripples may be present and enhance suspension of bottom sediment if the wave action is not intense enough to smooth over ripples, while the presence of ripples modifies the bottom roughness and thereby alters the bottom boundary layer (*e.g.* GRANT and MADSEN, 1982; SLEATH, 1984). Even in the absence of ripples, bed load and suspended load modify the near-bottom flow characteristics noticeably since sediment particles are heavier than water and collide with one another (*e.g.* KOBAYASHI and SEO, 1985; GLENN and GRANT, 1987).

Prediction and measurement of the net rate of cross-shore sediment transport are normally difficult. The net sediment movement tends to be the small difference between the large quantities of sediment moving forward and backward with the oscillatory wave motion, while the small difference depends on various additional effects such as currents, wave asymmetry, bottom slope and wave-induced mass transport (MADSEN and GRANT, 1976). Furthermore, the variation of the net sediment transport rate in the cross-shore direction needs to be predicted. The predicted cross-shore variation is substituted into the continuity equation for sediment to predict the change of the beach profile over a specified time interval which is much longer than the time scale associated with the wave motions. The change of the beach profile modifies the wave and current fields and resulting net sediment transport rate. As a result, the prediction process needs to be repeated from the beginning.

The prediction of the beach profile change will become much easier if it is limited to the erosion due to the net offshore sediment transport for which the direction of the net sediment transport is specified in advance. The models for beach and dune erosion proposed by KRIEBEL and DEAN (1985) and KOBAYASHI (1987) employ empirical formulas for the net offshore sediment transport based on the concept of equilibrium beach profiles. These simple models are very easy to apply but do not explain the mechanics of the net offshore sediment transport. STIVE and BATTJES (1984) assumed that the net offshore transport rate might be estimated from the time-averaged concentration of suspended sediment transported by the undertow induced by breaking random waves. The model based on the undertow alone was shown to yield reasonable agreement with the beach profile measurements made in large-scale and small-scale flumes. A conceptually similar but more complicated model was proposed earlier by DALLY and DEAN (1984). The effect of the first-order oscillatory velocity was included in a heuristic manner to produce the net onshore transport of suspended sediment. It should be mentioned that the vertical velocity distribution associated with the undertow in their model may need to be modified in light of the more recent work of SVENDSEN *et al.* (1987).

GUZA and THORNTON (1985a) presented field data on the water velocity field from a gently sloping beach with moderate wave heights. Various moments of the measured velocity field were calculated to estimate the net sediment transport rate on the basis of the total load model proposed by BAILARD (1981). The observed cross-shore velocity variance indicated the importance of the low-frequency component which was maximum at the shoreline, while the wind wave component was maximum offshore. Their data analysis suggested that both bed and suspended load were significant for the net cross-share sediment transport in which asymmetries in the oscillatory wave field caused the net onshore transport, while the interaction of the seaward mean flow (undertow) with waves produced the net offshore sediment transport. BAILARD (1987) presented similar field data and analysis. STIVE (1986) presented an analysis procedure for predicting the net cross-shore sediment transport and resulting beach profile change due to random waves by extending the analysis of GUZA and THORNTON (1985a) somewhat intuitively. Reasonable agreement was obtained between the predicted and measured beach profiles except that actual bar growth was not well predicted and the swash zone was excluded from the analysis.

SALLENGER and RICHMOND (1984) measured sediment-level oscillations in the swash zone of a high-energy, coarse-sand beach. The swash-zone profile was found to change its configuration in a rapid and well-organized manner. A similar field experiment was carried out by HOWD and HOLMAN (1984). Infragravity and lower frequency waves were found to influence patterns of erosion and deposition in the swash zone which were not directly related to the periodic saturation of the beach foreshore. On the other hand, KOBAYASHI and DESILVA (1987) computed the movement of individual sediment particles in the swash and surf zones on a sand beach under the action of a specified normally-incident monochromatic wave train by applying the numerical Lagrangian model for riprap movement on the slope of a coastal structure developed by KOBAYASHI and OTTA (1987). The computed displacements of individual sediment particles under the periodic wave action were used to predict the direction (onshore or offshore) and rate of the net movement of the sediment particles along the specified beach slope. Comparison was made with available data for which initially uniform beach slopes were exposed to incident monochromatic waves. The model was found to predict only the erosional trend of beach profile changes. It was suggested that the effects of permeability neglected in the model might cause sediment particles entrained in the uprushing water to be deposited in the region near maximum wave runup without being transported again in the downrushing water. LONGUET-HIGGINS (1983) showed that the mean onshore pressure gradient associated with wave setup in the surf zone drives a circulation of water in a porous beach with downward percolation in the upper part of the surf zone. In any case, more studies are needed to improve the understanding of sediment dynamics in the swash zone and better establish the landward boundary condition required for existing models of beach profile changes.

CONCLUSION

An attempt has been made to assemble and synthesize recent publications which may contribute to the improvement of our quantitative capabilities for predicting short-term and long-term shoreline changes due to the cross-shore sediment transport in the surf and swash zones on beaches. This review has been limited essentially to the cross-shore hydrodynamics of incident wind waves and low-frequency motions as well as the cross-shore sediment transport and resulting beach profile evolution, although the actual littoral processes are three-dimensional and unsteady, covering wide ranges of space and time scales. Even under the idealized two-dimensional and short-term conditions, our quantitative capabilities are not sufficient for predicting the beach profile evolution accurately and confidently. Future improvements, some of which have been discussed in this review, will require combined efforts of engineers, geologists and oceanographers by making the best use of mathematical and numerical methods together with comprehensive field and laboratory experiments.

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☐ RÉSUMÉ ☐

En réunissant et en synthétisant des résultats récemment publiés, on essaye d'améliorer la prédiction quantitative des changements qui affectent les plages par suite du déplacement des sédiments dans la zone du déferlement. Cette mise au point est limitée essentiellement au déplacement des sédiments perpendiculairement au rivage, en liaison avec la dynamique des vagues incidentes et l'agitation de l'eau consécutive au déferlement, et aux modifications qui en résultent dans le profil des plages. *(Roland Paskoff, Université Lumière de Lyon, France).*

☐ RESUMEN ☐

Se ha intentado sintetizar y relacionar las publicaciones que pueden contribuir a mejorar nuestra capacidad de predicir cuantitativamente cambios en la linea de costa debido a transporte transversal de sedimentos en la zona de surf y en el estrán de las playas. Esta revisión limitada a la hidrodinámica del oleaje incidente, movimiento debido al surf beat, asi como al transporte transversal de sedimentos y la evolución resultante del perfil de playa.—*Department of Water Sciences, University of Santander, Santander, Spain.*

☐ ZUSAMMENFASSUNG ☐

Es wurde der Versuch unternommen jüngere Publikationen, die einen Beitrag zur Verbesserung der quantitativen Vorhersage bei Küstenveränderungen leisten können, zu sammeln und zusammenzufassen. Der Reviewartikel bezieht sich allein auf Küsten- bzw. Küstenlinienveränderungen, die durch "cross-shore" Sedimenttransport in der Brandungs-und Wellenauflaufzone bedingt sind, d.h. es fand eine Begrenzung auf die hydrodynamischen "cross-shore"-Parameter in Interaktion mit der Wellen- und Brandungsbewegung, der Sedimentverlagerung und der daraus resultierenden Abfolge von Strandprofilen statt.—*Ulrich Radtke, Geographisches Institut, Universität Düsseldorf, F.R.G.*