Impact of beach scraping on near shore sediment transport and bar migration

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Abstract
This paper presents results from two sets of laboratory experiments at different scales that demonstrate a strong influence of beach scraping on sediment transport within the surf zone. For erosive conditions, the reshaping of the upper beach was found to prevent further migration of the offshore bar and reduce the offshore transport across the whole surf zone. For beach recovery tests, where the breaker bar was initially stable in the control tests, reshaping the upper beach induced rapid onshore migration of the bar. Thus, the reshaping tended to either stabilize the beach or enhance beach recovery over the surf zone. A detailed investigation of the hydrodynamics within the surf and swash zones showed that this effect was induced by the more dissipative swash zone reducing sediment concentrations within the wave backwash and within the surf zone. The experiments demonstrate the importance of the swash zone in influencing overall beach morphodynamics. Improving predictions of both beach erosion, accretion or bar behaviour therefore require inclusion of the swash zone in numerical models.

Keywords: Beach scraping, coastal erosion, swash zone, surf zone, longshore bars

1. Introduction
Beach scraping, the mechanical movement of sand from the lower intertidal zone to the upper beach or dunes, is a relatively common method of beach nourishment or beach protection, usually aimed at providing short term defence after severe erosion. It has been extensively used in NSW and QLD, but less so elsewhere in Australia, and is also used in the USA and elsewhere. The aim of the present paper is not to investigate the efficacy of beach scraping as a beach face nourishment technique, but to investigate the effect of beach scraping on the surf zone or nearshore morphology. Data from beach scraping studies in the field are relatively rare, and usually limited to the intertidal zone. Field data is also complicated by inherent variability in wave climate, longshore sediment transport and antecedent morphological conditions. This makes investigating the impact of beach scraping on the surf zone morphology difficult. A review of recent data is given by [7]. Extensive survey data from a recent beach scraping project at New Brighton, NSW, is presented by [10] and demonstrates current practice and impacts on beach face morphology. This paper utilises simplified laboratory conditions, at small and large scale, to study the change in nearshore morphological response induced by beach scraping, and to determine if changes in the hydrodynamics are consistent with the observed morphological changes. While scale effects are clearly present in laboratory studies, both the laboratory data sets discussed here exhibit an overall morphological response to changes in the incident wave conditions that is consistent with engineering experience and observations from nature. Thus, we expect the observed characteristics of the study to be relevant to natural conditions.

During recent years important progress has been made in the understanding of the sediment transport and hydrodynamics on the beach face (loosely defined as the swash zone) that are reflected in several review papers [6, 8, 9]. However, there are still many uncertainties to be solved with respect to the swash zone, especially, with regard to sediment dynamics. Two aspects relevant to the present work are: i) the need for advances in the knowledge of sediment transport in the swash zone, and ii) that the swash zone must be viewed as an integral part of the surf zone and dune region and the effect of these areas on the swash zone and vice-versa is not well understood [9].

The dynamics of the swash zone are not only important because of their local effect and influence (e.g. wave inundation, overtopping and overwash, beach face evolution, dune erosion and beach recovery) but also because the dynamics can directly affect processes occurring in the surf zone as a whole. For example, dune erosion is a predominant swash zone process and the sediment mobilized from the dune may feed sandbars, modifying the surf zone morphodynamics. Conversely, onshore bar migration and welding to the beach-face occurs during accretive conditions, where the swash and surf zone processes are both important in controlling the morphodynamics [1]. Broad scale hydrodynamic numerical models have been proposed that include swash zone hydrodynamics with different degrees of complexity [11]. However,
while these models are focused on improving model performance by including specific processes happening in the swash region, the influence of swash conditions over the overall beach morphodynamic has not been properly accounted for, or specifically investigated, as yet.

2. Methodology

Data from two sets of large-scale experiments and one small scale experiment are presented and discussed here in the context of beach scraping. The large scale experiments [3] investigate the swash and surf dynamics under the same hydrodynamic forcing but with two different swash zone morphological conditions, one of which was created by manual reshaping of the sub-aerial beach face, as might be performed during beach scraping. Results from the more dissipative swash zone conditions (a more mildly sloping beach face) are compared to a second set of experiments [2] which shows the usual offshore sand bar migration under almost identical hydrodynamic forcing. The small scale experiments [5] investigated the influence of beach reshaping on beach recovery after a period of erosive wave conditions. Full details of the experiments are presented in the papers cited above; a summary of details relevant for the present work is provided here.

2.1 Small scale experiments

Small scale experiments were conducted in the UQ wave flume to investigate the influence of reshaping the beach face on the surf zone morphology. The overall setup comprised a mobile fine sand beach \((d_{50}=0.2 \text{ mm})\), set with an initial gradient of 0.1. The water depth at the toe of the beach was 0.34 m, with waves generated at the far end of the basin in a water depth of 0.55 m. The wave flume was divided into sections to run two experiments on adjacent beaches simultaneously. The experiments were performed by running monochromatic wave conditions until an equilibrium barred beach profile was achieved. The beach was then reshaped with a smaller gradient in the swash zone and then subject to milder wave conditions, simulating recovery. The adjacent beach was not reshaped as a control.

2.2 Large scale experiments

The data were obtained in the Canal de Investigacion y Experimentacion Maritima (CIEM) at the Universidad Politecnica de Cataluna (UPC), Barcelona. It is a large-scale wave flume of 100 m long, 3 m width and 4.5 m depth. The data were collected during the EU Hydralab III project SCESE project (Suspended Concentration Events in Swash Experiments). Moderately energetic random waves were generated \((H_s = 0.46 \text{ m and } T_p = 4.4 \text{ s})\), repeating the same wave realization for a series of 12 tests (the same wave time series is repeated 12 times). Each test comprised 500 waves, with a total duration of around 31 minutes (around 6 hours of total experimentation time). A second set of experiments is used for comparison, the data collected comes from the Hydralab III SANDS project (Scaling and Analysis and New instrumentation for Dynamic bed testS). Similar wave conditions were generated, repeating the same wave realization for a series of 47 tests. Each test comprised 500 waves, with a total duration of around 27 minutes (around 21 hours of total experimentation time). A summary of the wave generation parameters is given in table 1. The random wave time series correspond to a Jonsdew spectrum \((\gamma = 3.3)\).

Table 1. Measured wave conditions during experiments

<table>
<thead>
<tr>
<th>Experiment</th>
<th>(H_s) (m)</th>
<th>(T_p) (s)</th>
<th>Water depth (m)</th>
<th>Iribarren num ((\xi))</th>
</tr>
</thead>
<tbody>
<tr>
<td>SANDS</td>
<td>0.53</td>
<td>4.14</td>
<td>2.47</td>
<td>0.47</td>
</tr>
<tr>
<td>SCESE</td>
<td>0.48</td>
<td>4.4</td>
<td>2.50</td>
<td>0.53</td>
</tr>
</tbody>
</table>

The initial experimental set up corresponds to a constant sloping beach with a gradient of 1/15. The beach was made of commercial well-sorted sand with a medium sediment size with \(d_{50} = 0.25 \text{ mm}\). The cross-shore coordinate \((x)\) and vertical coordinate \((z)\) have their origin at the initial still-water shoreline, to facilitate the comparison among experiments, and are positive shoreward and upward, respectively. The beach evolution along the center-line of the wave flume was measured with a mechanical wheeled bed profiler that measures both the sub-aerial and submerged beach elevation; more details can be found in [4]. The overall vertical profile accuracy is estimated to be ±10 mm.

During the SCESE experiments, a bar was generated during test 1 and migrated seaward until the end of test 8. After completion of test 8 (4.13 hours of experimentation time), the sub-aerial beach face above the SWL was manually reshaped to obtain more dissipative conditions within, and only within, the swash zone. Figure 1 shows a detailed view of the profile before and after manual reshaping.

![Figure 1. Detail of the manually reshaped shoreface after test 8 of the SCESE experiments. Measured beach profile after test 8 (dash-dotted line) and manually-reshaped beach profile (dotted line).](image-url)
The tests continued with identical incident wave conditions for a further four runs to investigate the effect of the new morphological swash conditions on the sediment transport and evolution of the existing offshore sandbar. Beach profiles were measured after tests 1, 2, 4, 6, 8, 9, 10 and 12, corresponding to experimentation time $T_{\text{exp}} = 0.52, 1.03, 2.07, 3.1, 4.13, 4.65, 5.17$ and 6.20 hours. These data are compared to those obtained from nearly identical wave conditions, but without beach reshaping, using the bar dynamics measured from the 47 tests in the SANDS experiments.

Water surface elevations along the flume and in the surf zone were obtained from resistive wave gauges distributed along the wave flume at cross-shore. For the SCESE experiments, detailed flow and sediment concentration measurements in the inner surf and swash areas were made both before and after manual reshaping. The water surface elevation in the inner surf and swash zones was measured by Acoustic Displacement Sensors. The flow velocity was measured by a series of Acoustic Doppler Velocimeters (ADV) while the suspended sediment concentration was measured using Optical Backscatter Sensors (OBS). The ADV, OBS and ADS were collocated in the cross-shore, and in order to obtain a high spatial resolution during the experiments and to avoid scour and flow disturbance, the ADVs were located close to one of the flume walls, while the OBSs were located at the same cross-shore location and vertical elevation with respect to the bed level, but close to the opposite wall. To ensure consistency in measurement at different tests, the vertical elevations with respect to the sandy bed were checked at the beginning of each test, with collocated instruments adjusted accordingly to the same initial elevation at the commencement of each test.

3. Morphology results

3.1 Small scale experiment

The evolution of the bathymetry in the initial small scale experiment is shown in figure 2. The initial planar beach evolved to form an equilibrium barred beach profile. The upper beach face was then significantly flattened and reshaped to a milder slope, with a gradient similar to that in the inner surf zone. Milder wave conditions were then run to simulate a recovery phase. Subsequently, the nearshore bar migrated rapidly onshore and the beachface berm accreted significantly. Over longer durations, the bar tended to stabilise in position, but the beach berm continued to grow. The control beach, subject to the same wave conditions and with no adjustment to the beach face profile, showed little subsequent change in the swash zone morphology and slower onshore bar migration.

3.2 Large scale experiments

Figure 3 shows the temporal variation in wave height and the beach profile for the SANDS experiment, which represents the control condition, i.e. no modification to the beach profile. At the outset, wave breaking occurred at around $x=-12$ m, and a small bar started to be generated around the breaker location, with the crest located at $x=-10.73$ m, figure 3b. The bar crest location is defined as the location of the maximum bar elevation with respect to the initial planar bed. As the experiment proceeded, the bar moved offshore, as did the breakpoint, and by the end of test 9 ($T_{\text{exp}}=4.05$ h) the bar crest was located at $x=14.25$ m with a bar crest elevation above the initial beach profile of 0.33 m. The bar location continued to migrate seaward over time, with the bar increasing in volume. The wave breaking location similarly migrated seaward with the bar crest location. This behaviour is consistent with many previous experimental studies and with the behaviour of bars on single-barred natural beaches. After the complete sequence (test 47, $T_{\text{exp}}=21.15$ h), the bar crest was located at $x=-16.61$ m with a bar crest elevation above the initial beach profile of 0.55 m.
Similar to figure 3, figure 4 illustrates the significant wave height distribution and beach profile pertaining to the SCESE experiments, which includes the reshaping test sequence. From test 1 to test 8, the significant wave height and beach profile behaviour is very similar to that of the previous SANDS experiments. A bar generated close to the initial breaking location, and the bar and the breaking location then migrated seaward during the subsequent tests. After test 8 (T_exp = 4.13 h) the bar crest was located at x=-12.47 m with a crest elevation above the initial profile of 0.39 m. The inner surf and low and mid swash zones also showed similar amounts of erosion to the SANDS tests, with a shoreline retreat of 1.37 m, while the upper swash zone experienced a small accretion of around 0.02 m.

After test 8 (t=4.13h), the sub-aerial beach profile above the SWL was manually reshaped to obtain a more dissipative lower swash zone, as illustrated in figure 2. No change to the profile was made offshore of the SWL. Following this change in the swash zone morphology, the bar migration rate reduced very significantly during the subsequent tests (9-12) and ceased almost completely. Simultaneously, the morphological response in the swash region changed, becoming relatively stable in the lower swash zone, with only minor erosion, but with a change to moderate accretion in the upper swash zone. This is further illustrated in figure 5, which shows that time-variation in the bar position and the elevation of the bar crest. After reshaping of the upper beach face, the bar migration slowed significantly, and ceased for the remaining test duration, and the crest elevation also ceased increasing. Unfortunately, testing ceased slightly too early to definitively demonstrate this effect. Nevertheless, in conjunction with the small scale tests, the reshaping appears to have a clear impact on the surf zone morphology. This is investigated in greater detail by considering the sediment transport rates and the near bed hydrodynamics and sediment transport.

Cross-shore sediment transport rates (Q) were computed from the measured beach profiles using the balance between bed-level changes and sediment transport gradients:

$$Q(x) = Q(x_{-i}) - p \int_{x_{-i}}^{x} \frac{\Delta z}{\Delta t} dx$$  \hspace{1cm} \text{(1)}$$

where Q(x) is the integral volume of sediment transport (m$^2$/s) at position x, $\Delta z$ is the difference in bed elevation (m) between measured profiles, $\Delta t$ is the time difference (s) between measured profiles and p is the solid fraction, approximately 0.6 for the laboratory sand. A known boundary condition needs to be set (Q(x) = 0) at either the landward or seaward end of the beach. We used a condition of no transport landward of the run-up limit. A correction is introduced in the calculated Q(x) to obtain zero sediment fluxes across the boundaries [4] which distributes measurement errors evenly across the profile.

Figure 6 shows the computed sediment fluxes for the SCESE experimental data before and after manual reshaping of the swash morphology. Before reshaping, the sediment fluxes show strong offshore transport in the surf zone, with a negative peak close to the wave breaking location and landward of the bar crest. Strong offshore transport also occurs in the inner surf and lower swash zone. The mid and upper swash areas (x ~ 3 to 8 m) experienced positive (shoreward) sediment fluxes, consistent with the berm formation noted above. This combination of shoreward transport in the upper swash zone in conjunction with offshore transport in the lower swash region, i.e. a steepening of the upper beach face during moderately erosive conditions in the absence of dune or scarp erosion, is a common feature of both laboratory experiments and natural beaches.
After reshaping of the beach-face, and under the same hydrodynamic forcing, very significant changes in the sediment flux occur in the surf and swash zones as a result of the new beach-face conditions. Close to the bar location, the offshore transport reduces by a factor of 4, consistently with the observed reduction of the rate of bar migration. Further, the transport direction is reversed in the lower and mid swash areas, with accretion occurring, in contrast to the erosive behaviour that occurred prior to reshaping. The point of inversion between shoreward sediment transport, in the upper swash, and seaward transport, in the lower swash, moves further seaward after reshaping by about 2 m, into the lower swash zone and inner surf zone. Therefore, the direction of transport in the inner surf zone and the lower swash zone changes to onshore. In addition, the location of the maximum rate of onshore transport in the upper swash zone is translated from \( x \approx 5 \) m before reshaping to \( x \approx 2 \) m after reshaping, and the magnitude of the shoreward transport increases. Overall, conditions become significantly less erosive, as expected and as intended by reshaping the swash zone.

These changes in the surf zone sediment transport rates appear to be closely linked to changes in the swash zone hydrodynamics which are induced by the beach reshaping. In particular, the degree of swash-swash interaction changes, the frequency of large backwashes is reduced and sediment concentrations are also altered. In combination, these lead to a reduction in the overall offshore transport. Each test has the same wave conditions, which are highly repeatable between tests. Therefore, direct comparison of the hydrodynamics and sediment transport is possible before reshaping and after reshaping.

![Graph](image_url)

Figure 6. Cross-shore distribution of sediment transport computed from bed evolution measurements at the experimentation time interval indicated in the legend and during the SCESE experiments. Reshaping occurred after 4.13 hrs.

Comparing, on figure 7, ensemble averaged values before and after reshaping, shows that relatively little variation occurs in the water surface elevation, the differences being within the inter-test variability. The measured velocity shows larger variations, and particularly negative velocities are larger before reshaping. This is consistent with the reduction in the magnitude of the largest backwashes. The net result is larger negative (offshore) sediment transport before reshaping, induced by the coincidence of high SSC with high negative velocities from the stronger backwashes. The integral suspended sediment transport for the whole time series at this location is twice as large in the offshore direction as that before reshaping. This, in turn, results in less sediment being transported from the swash to the surf zone after the reshaping and the consequent influence on the sandbar migration. The differences in ensemble averaged suspended transport at this location before and after reshaping represents a 179% variation with respect to mean values and is, therefore, considered to be a direct consequence of beach face reshaping and cannot be attributed to inter-test variability.

5. Summary

Results from two sets of laboratory experiments at different scales demonstrate a strong influence of beach scraping on sediment transport within the surf zone. During erosive wave conditions, the reshaping of the upper beach was found to prevent further migration of the offshore bar and reduce the offshore transport across the whole surf zone. For beach recovery tests, where the breaker bar was initially stable in the control tests, reshaping the upper beach induced rapid onshore migration of the bar in comparison to a control case. Thus, the reshaping tended to either stabilize the beach or enhance beach recovery over the surf zone. A detailed investigation of the hydrodynamics within the surf and swash zones showed that this effect was induced by the more dissipative swash zone resulting from the milder sloping beach face. This reduced sediment concentrations within the wave backwash and within the surf zone. The experiments demonstrate the importance of the swash zone in influencing overall beach morphodynamics, not just the beach face itself. Improving predictions of beach erosion, accretion or longshore bar behaviour are therefore likely to require the inclusion of the swash zone hydrodynamics in numerical models.

The potential for beach scraping to alter the morphodynamics of the whole surf zone needs to be considered in future practice. Continuous small scale scraping of sediment may provide a better mechanism to encourage the recovery of beaches, as opposed to a single larger scale project. This could be done as part of normal beach management processes. A full scale field trial would be a useful addition to current knowledge, combined with an appropriate monitoring scheme to determine changes in surf zone morphology.
6. References


