On the role of a permeable groyne in beach morphodynamics during sea-breeze events in Yucatàn, Mexico

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ABSTRACT
The north coast of the Yucatàn peninsula in Mexico is vulnerable to strong sea breezes, which in turn causes high waves, driving high rates of erosion due to littoral transport. To find a solution for erosion problems caused by currently applied measurements, a permeable groyne was introduced, tested and monitored during a 24h experiment. Concluded was that the permeable groyne has the potential to reduce downdrift erosion problems due to its permeability. However, long term effects could not be properly assessed and requires a follow-up study.

Keywords
Permeable groyne, longshore sediment transport, erosion, Yucatàn, human intervention, sea-breeze events

INTRODUCTION
As population increases in coastal areas, pressure on currently existing ecological systems increases, resulting in human interventions. Particularly low-lying areas such as the Yucatàn peninsula, situated in Mexico between the Gulf of Mexico and the Caribbean sea, as seen in Figure 1, are vulnerable. Poor coastal management and human interventions have created a fragile ecosystem without a proper monitoring and management system, resulting in increased risk of floods and vulnerability of the coast (Appendini et al., 2012).

The geographic orientation of the Yucatàn coastline makes it particularly vulnerable to wave- and storm activity heading from the Gulf of Mexico to Yucatàn. These activities cause high pressure systems to form and send strong winds predominantly from the northeast (so called *sea-breeze events*) towards the peninsula, driving strong waves towards the Yucatàn coast. This results in sediment transport alongshore to the coast and causes beach erosion along the coast. In this vulnerable ecosystem, a high rate of urbanization along the Yucatàn coast related to increased economic and touristic activities have caused a significant change of the coastline (Meyer-Arendt, 2001). These economic activities mostly stir the construction of ports, harbors and vacation homes, altering the shorefront and interrupting the natural processes of alongshore sediment transport.

In order to counter the effects of beach erosion, various local measures have been taken by property owners. One predominantly applied measures are impermeable groynes, to counter beach erosion. However, these impermeable groynes stimulate seaward loss of sand and most important, stimulate downdrift erosion alongshore of the structure (Bakker, 1984), thus increasing the erosion problems along the Yucatàn coast.

A solution to the downdrift erosion problems has been proposed in the form of permeable groynes. Whilst already being applied in the Netherlands in the form of pilegroynes (Bakker, 1984), just only recently experiments into groynes have been performed in Mexico. Therefore, a permeable groyne was investigated and compared to a previously studied impermeable groyne in order to assess if permeable groynes are a viable solution to prevent beach erosion as well as prevent downdrift erosion problems.

STUDY AREA
The area in which the study was performed, is the Sisal area, a small fishing village at the northern coast of Yucatàn, about 50 km from the state capital Mérida, which can be seen in Figure 1. The coast at which Sisal is situated, is characterized as a low-lying coastal area, consisting out of 59% coastal lagoons and 41% direct sandy coast front (CINVESTAV, 2007). Also, the area is situated in a microtidal environment characterized by a small tidal range varying between the 0.1 m for neap tides and 0.8 m for spring tides (Cuevas-Jiménez et al., 2009).

Whilst the Sisal area is sheltered from big deep water swells and waves coming from the Gulf of Mexico by a large and shallow continental shelf called the Yucatàn shelf or the Campeche Bank (Enriquez et al, 2010), the area around Sisal is subject to high wave events caused by the sea-breeze events. These sea-breezes with an average windspeed up to 35 m/s start in the late morning and end around the beginning of the evening. The sea breezes

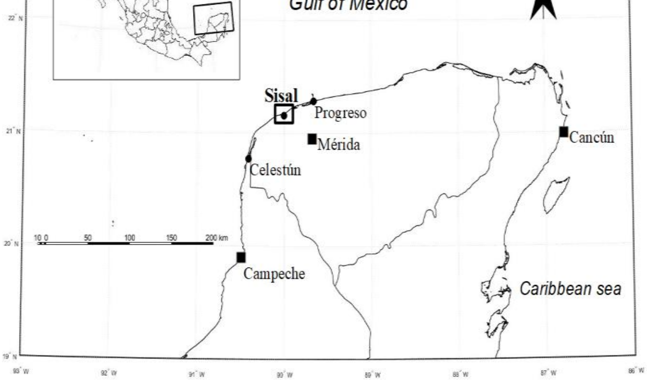

Figure 1. Location of the research site within Mexico

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increase wave height significantly, especially in the afternoon when the wind waves reach the shoreline (Appendini et al., 2012).

METHODOLOGY

Theoretical framework

The highly energetic wind waves the study area are created when deep water waves are subject to wind, and the transfer of friction force between the wind and the waves drives the waves proportional to the direction of the wind. When the deep water waves enter shallow water, the waves are affected by the decreasing depth because of the increase in friction between the waves and the seabed. In order to compensate for the decreasing velocity near the seabed, causing a velocity gradient in the wave, the waves not only increase in height (shoaling), but also slightly change direction (refraction), making the waves hit the shore in an angle or obliquely. (Longuet-Higgins, 1970).

Obliquely-breaking waves introduce a flow not only in the landward direction, but also in the direction along the shore, which is called longshore drift. The friction between the wave and the seabed stirs up sediment particles, which are then transported with the wave back to sea, as well as along with the longshore current, causing littoral drift, or alongshore movement of sand (Hanson & Kraus, 1990).

The magnitude of the littoral drift along the coast depends on the amount of blockage of the sediment in the alongshore direction. By blocking the sediment flow, a structure can trap sediment on the side directly in the drift (updrift side), whilst due to wave breaking and littoral drift, the other side is heavily eroded. A permeable structure may therefore be able to reduce the amount of erosion on the side not exposed to sediment drift (downdrift side) because of the sediment supplied through the structure.

Experiment set-up and data collection.

For the experiment, a permeable groyne consisting out of concrete interlocking elements was proposed. The blocks were x-shaped blocks, interlocking with each other to form

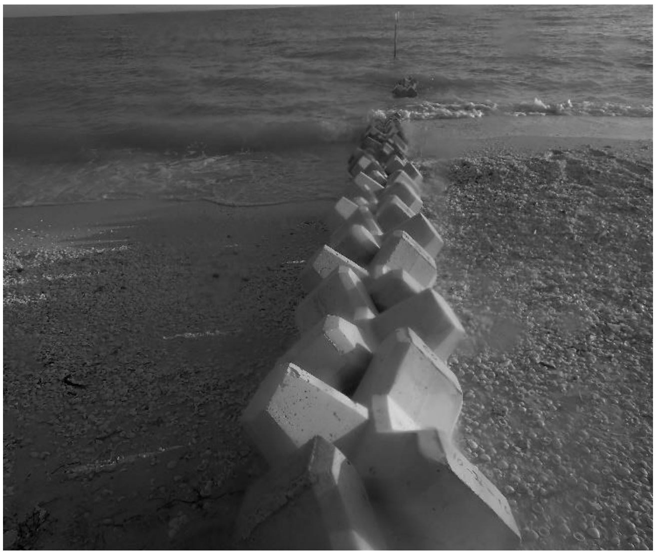

Figure 2. A photo of the experimental site during the experiment with the permeable groyne (photo: A. Hofman).

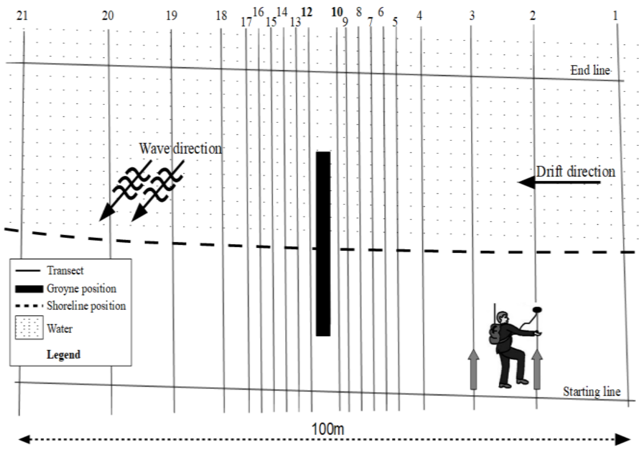

Figure 3. Schematic top view of experimental site, showing the shoreline, the permeable groyne, numbered transects (#1-#21) as well as the starting and end lines of the cross-shore walking paths.

a rigid structure, but leaving enough space in between for water and sediment to pass through. An impression of the elements in the permeable groyne can be seen in Figure 2.

Real Time Kinematic (RTK) surveying was used to monitor changes in beach profile. RTK survey is a position data survey technique using global navigation satellite systems (GNSS/GPS) to determine position and height of the observer. The beach profiles were measured along 20 surveying lines (transects), 10 on the updrift- and 10 on the downdrift side of the permeable structure. The transects were spaced in accordance to Figure 3. All measurements were conducted following the same procedure, using two reference points: one fixed and pre-measured point and a second non-changing control point. After measuring the control point, the bed level height was measured using a Leica GS14/CS15 GPS RTK system by walking along the transect and measuring bed level at positions taken at 1 sec interval. Wind conditions were measured by a wind station present at the experimental site. Wave conditions were measured by using a Nortek Vector current meter and an ADCP current profiler.

Before starting, the natural variability in bed level was assessed by conducting four measurements before starting the experiment. During the deployment of the structure, the beach was monitored each two hours for 24 hours, starting at 8:00 and finishing at 8:00 the other day. After the experiment, six measurements in the three days after the experiment were taken in order to assess beach resilience to the introduction of the structure. After each measurement, data was verified and corrected in order to compensate for errors in position and height.

Finally, a bandwidth of natural variability was empirically established using the starting measurements to investigate whether or not the measured transect was affected by the permeable structure. The bed level variability was checked against empirically established upper and lower limit values. If at least 90% of the values fell within the upper limit and if at least 90% of the values fell within the lower limit, the bandwidth was accepted as the bandwidth for natural bed level variability.

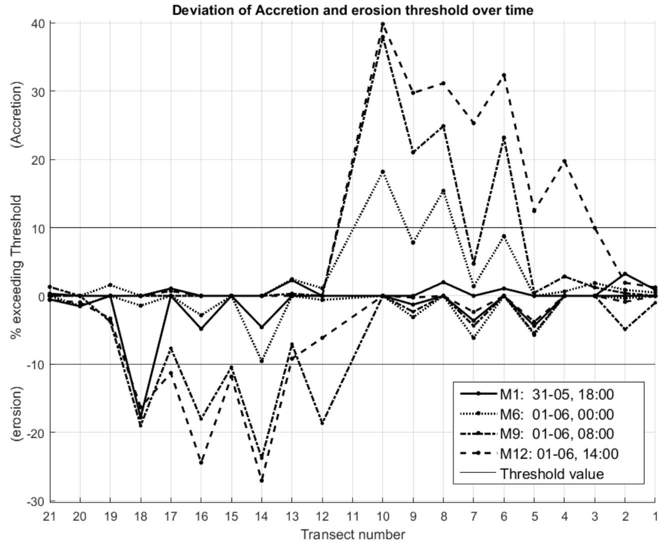

Figure 4. Percentage of measured points exceeding the established erosion/accretion bandwidth of 0.09 m for each transect

RESULTS

Validation of natural variability of the beach

Firstly, the correlation between wind speed and wave height was investigated to check whether or not the wave height was strongly affected by the wind speed. In this case, for 10 days of data a correlation between the two of 0.79 was found, indicating a strong correlation. At the peak of the sea breeze intensity, wave height is at its maximum and increases on average from 0.35 m in calm weather to almost 0.8 m during sea breeze-events. Wave height was tied to the wind speed, which mostly ranged from 2-4 m/s in calm weather and up to 10-14 m/s in sea-breeze events.

The bandwidth of natural bed-lever variability was found to hold for a daily variability of 0.09 m bed level change for accretion of sediment as well as for erosion. These values were taken as the limit to assess whether or not the bed level at a certain transect was affected by the groyne.

Finally, it is known that under sea-breeze conditions, the shoreline often oscillates between the Sisal jetty and the Sisal pier (Torres-Freyermuth, *pers.comm.*). As the measured site is located in between the Sisal jetty and pier, it implies that at the measured site due to oscillation in the shoreline position, no net erosion or accretion occurs over a longer period of time and that natural variability of the beach for the most part will depend on the intensity of the daily sea breeze-events.

Impact of a permeable groyne during one sea breeze-event

The natural conditions regarding wind and wave height were found to be typical for a sea breeze-event. The wind speed was seen to be low in the morning, picking up around the afternoon and increasing to 11 m/s. The wave height followed the pattern of the wind by being low in the early morning and picking up in the afternoon to around 0.35 m. The ADV also showed a longshore velocity current from east to west, a velocity which was almost zero during calm period and increasing during sea breeze-events in a westward direction

As the permeable groyne was introduced to the system, it was seen from the measured RTK-data, shown in Figures 4 and 5, that the groyne altered the bed level around the groyne significantly. The elements of the permeable groyne are blocking sediment from the updrift side, showing accretion over time on transect 10, and some erosion, although variable, on transect 12. However, transects at the far up- and downdrift sides are almost not affected by the presence of the groyne as they never exceed the established threshold, as can be seen from Figure 4. Therefore, it may be assumed that in the far up- and downdrift areas, the profile changes are assumed to be due to natural variability.

Transects affected by the presence of the groyne show development over the course of 24h, although the rate of accretion and erosion varies over time owing to changing wave conditions. Updrift transects (3 to 10) are increasing in volume, and the downdrift transects (12 to 19) show erosion over time. The direct downdrift transect (11) displays not only erosion, but also accretion over time, indicating a connection between the updrift and downdrift side through permeability. The characteristic shape of the seabed is however comparable to the one caused by a permeable groyne.

DISCUSSION

The wind and wave data obtained during the experiment seems to confirm that the longshore drift increases with the longshore velocity and establishes the relation that the amount of littoral drift is dependent on the wind speed. When the amount of drift and wave action is increased in a sea breeze-event, it is shown that the sediment capture rate increases strongly and the downdrift side erodes, corresponding with the behavior of an impermeable groyne. However, after the sea breezes have finished, it is seen in Figure 5 that some of the captured sediment is transported to the downdrift side, indicating that the permeability of the groyne helps in preventing erosion on the downdrift side.

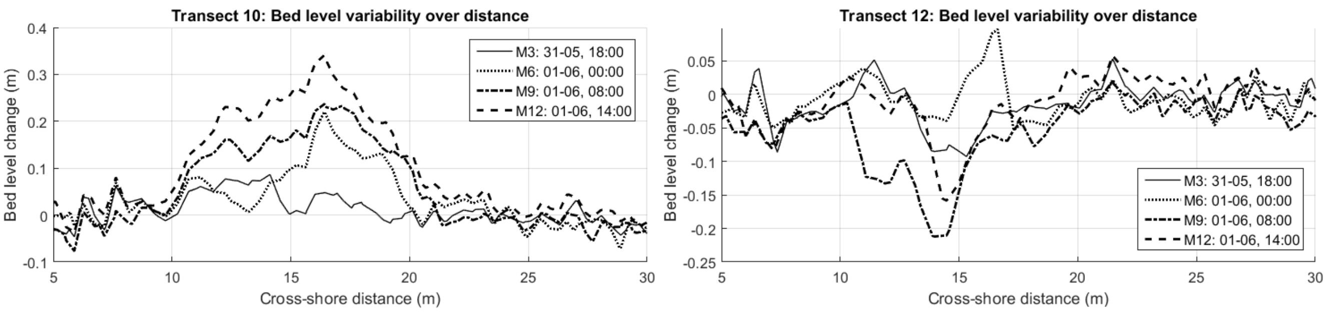

Figure 5. Change in bed level in the direction of the transect (cross-shore direction) with respect to the first measurement. Transect 10 is the transect directly updrift of the groyne, transect 12 is the transect directly downdrift of the structure.

Comparing the results for an impermeable groyne and a permeable groyne confirmed that the permeable groyne had a lesser impact on the shoreline because of a lesser sediment budget trapped by the permeable groyne, and the ability of the sediment to flow between the updrift and downdrift side of the groyne. However, the characteristic shape of the beach did not change, because a pattern of accretion on the updrift side and erosion on the downdrift side was still witnessed.

Finally, some remarks must be made on the obtained results of this research. The natural bandwidth was established for the purpose of assessing the impact of the natural variability. However, as it was only based on a limited amount of measurements, the natural variability may be much larger and is heavily dependent on the conditions in which the measurements are done. Also, this experiment was conducted over a 24h-period and thus no good estimate can be given of the performance of the permeable groyne on the long term. Further investigation is needed to be able to compare the long term results to other papers found on the long-term effects of an impermeable groyne on the longshore sediment transport.

CONCLUSION

The role of groynes in Mexican coastal protection is a double role. Whilst groynes are used by local property owners to prevent beach erosion, the groynes also introduce problems which come to be with these measures. Therefore, a solution in the form of a permeable groyne was proposed and tested during a 24h experiment in which the effect on beach erosion was continuously monitored by using RTK surveying methods.

By studying the area and looking at wind and wave data, it was assessed that wind significantly affected wave height. In turn, wave height affects sediment transport alongshore, which, under effect of a blocking structure, may introduce erosion problems into the system because of blockage of sediment and thus lessening the sediment budget flowing alongshore. In order to assess natural variability of the beach, a bandwidth was established to determine to which degree a structure affected beach development in the area.

The data of the 24h-experiment showed clearly that beach development was significantly affected by the introduction of a permeable groyne. Next, it was found that whilst the permeable groyne had an advantage over the impermeable groyne in capturing lesser sediment and allowing the downdrift section to receive sediment, the effect of the permeable groyne saw a similar development of beach profile as the impermeable groyne. However, because of the short term in which the experiment was conducted and the limited amount of measurements taken, it could not be said for certain what the long-term effects of the permeable groyne in the study area would be.

ROLE OF THE STUDENT (MANDATORY)

I, Anne Hofman, was a BSc-student Civil Engineering at the time of conducting this research. Under the supervision of Dr. Ir. Pieter Roos from the University of Twente and Dr. Alec Torres-Freyermuth of the Laboratorio y Ingeniería de Procesos Costeros (LIPC), part of the Universidad Nacional Autonoma de Mexico (UNAM), I did my research in Mexico. Together with Alec, I established the subject of this paper. The experiment was set up and conducted by me using the help of the teachers, employees and students from the LIPC. Processing of the measurements, drawing conclusions and writing the report were conducted by me and iterated using feedback from my supervisors. Finally, this paper was also written by myself and again improved with feedback from my supervisors.

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