A numerical study on the role of cross-shore profile shape on wave run-up

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Introduction

Wave runup is a fundamental process in shaping the beachface and in causing dune and beach erosion, overtopping of coastal structures and flooding of coastal region. Research has related runup to wave parameters and beachface slope, α (Stockdon *et al.,* 2006). Despite the widespread relationships between runup and α, the role of this parameter is not well understood (Senechal *et al.*, 2011). Natural beaches present **complex cross-shore profiles** characterized by the presence of sandbars. The strong dependence between wave breaking and water depth implies that the sandbars presence can determine the characteristics of wave breaking and therefore of runup, as recent field experiment showed (Guedes *et al.*, 2012, 2011). With the aim of **improving the understanding of the role of the cross-shore beach profile on runup elevation (R_{up})**, this study analyze the influence of several geometric variables of barred beach profile over wave runup.

Methods

We simulate swash motions on different single-barred beach profiles using SWASH, a one-dimensional nonlinear shallow water equations model (Zijlema, 2011). Numerical features are summarized in Table 1.

Vertical layer	2
Cell size	L/60 (L= wave length)
Cell size at swash zone	1m
Computational time	7200s
Manning's roughness coeff.	n=0.0019 Zijlema (2011)

Table 1. Numerical features summarize

Bathymetries: The real beach profile of Miyazaki harbor (Enckevor et al., 2004) in Japan is taken as "Base" profile (P1). From the base profile, 13 new cross-shore shapes (Pi) are set up modifying: the **bar crest depth** (hc) and **position** (xc), the **bar trough depth** (ht) and **position** (xt), the **beachface slope** (α), the **offshore slope** (β) and **tidal level** (Level).

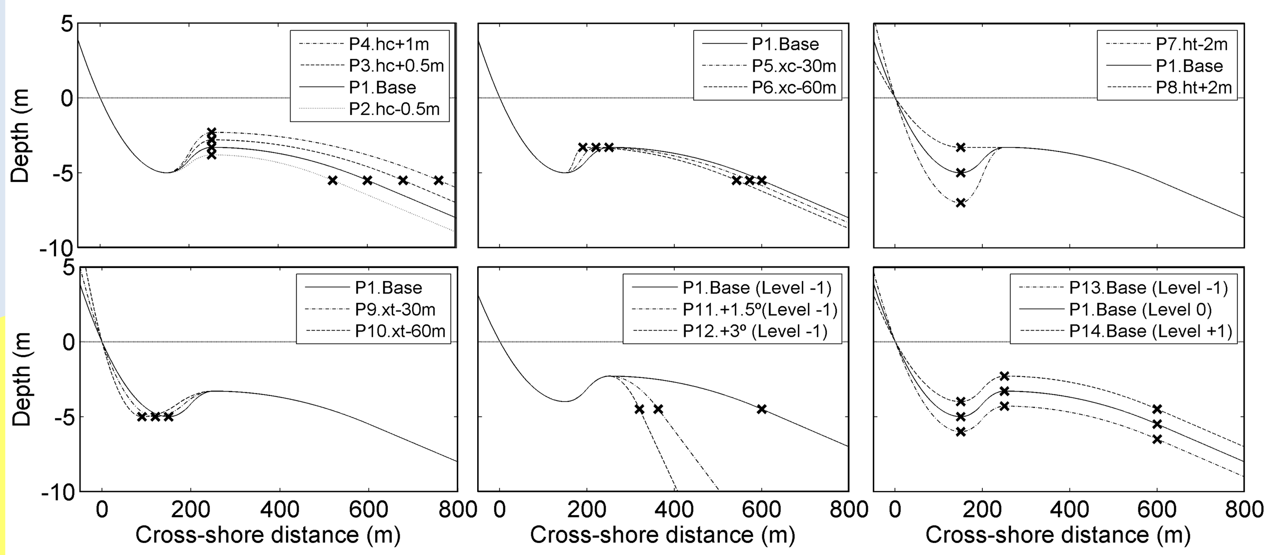


Figure 1. Study barred beach profiles. They are defined by a piecewise analytical function (Caballeria et al., 2003). α is defined between SWL±1m and β between the first and the last points of exponential decay.

Wave characteristic: A wave generation algorithm able the reproduce 2nd order waves (Longuet-Higgins & Stewart, 1960) forces the numerical simulations. The dimensionless generation depth (kh) was π/2, the maximum that allow the correct long wave transformation of these externally generated waves up by SWASH (Jalón-Rojas, 2013). **Nine wave cases** are defined by 3 characteristics periods (7, 9 and 11 s.) and 3 characteristic Ursell number (0.75, 0.9 and 1.1) of sea states of Miyazaky beach (Enckevor et al., 2004).

Analysis techniques:

- **R_{up} calculation:** point where fluid thickness exceeds 0,06 m, a value favourably compared to laboratory observation in Ruju (2013). The independence of wave sequence in runup calculation was tested (Jalón-Rojas, 2013).
- For each cross-shore profile, we represent the **significant runup (*R_s*,** 4 standard deviation of the R_{up} time series) for each **wave energy $(H_0L_0)^{1/2}$** *(*)*.
- In order to interpret the results, we calculate the **position of wave breaking**, as the point where $\sqrt{H_{MO}/H_0} = 0.75$ *(**)*, and the energy spectrum (FFT) at a point behind the bar (Fig. 2) to analyze the bar energy dissipation.

(*) H_0 is the generation significant wave height; L_0 is the generation wave length.
(**) H_{MO} is the wave height of zero-order defined as $H_{M0} = 4\sqrt{\sum E(f)\Delta f}$;

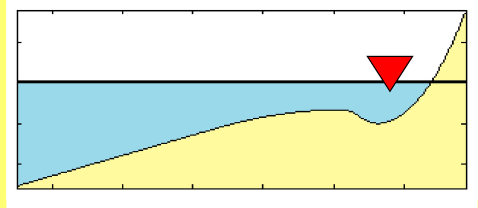


Figure 2. "Gauge" position to calculate energy spectrum.

Results

- R_{up} increases with increasing wave energy ($\sqrt{H_0L_0}$). In general, only the most energetic waves induce significant differences of R_{up} over different cross-shore geometries.
- **Shallower bar crests** (hc, Fig. 3.1) cause significant smaller R_{up}, about 0.5m, for energetic waves ($\sqrt{H_0L_0} > 10m$) and slightly higher R_{up} for $\sqrt{H_0L_0} < 10$
- **Shallower bar troughs** (ht, Fig. 3.3) result in smaller R_{up}, with R_{up} differences of up ~25%.
- **Bar crest position** (xc, Fig. 3.2) does not have any effect in R_{up}, while **trough position** (xt, Fig. 3.4) affects runup. Steeper **face-slopes** (α) provide higher R_{up}.
- The **offshore slope** (β, Fig. 3.5) mainly influences R_{up} for the most energetic waves, resulting highest R_{up} in steeper β.
- **Low tides** induce smaller runup than **high tides**, with R_{up} differences of up 0.5 m for the most energetic waves (Fig. 3.6).

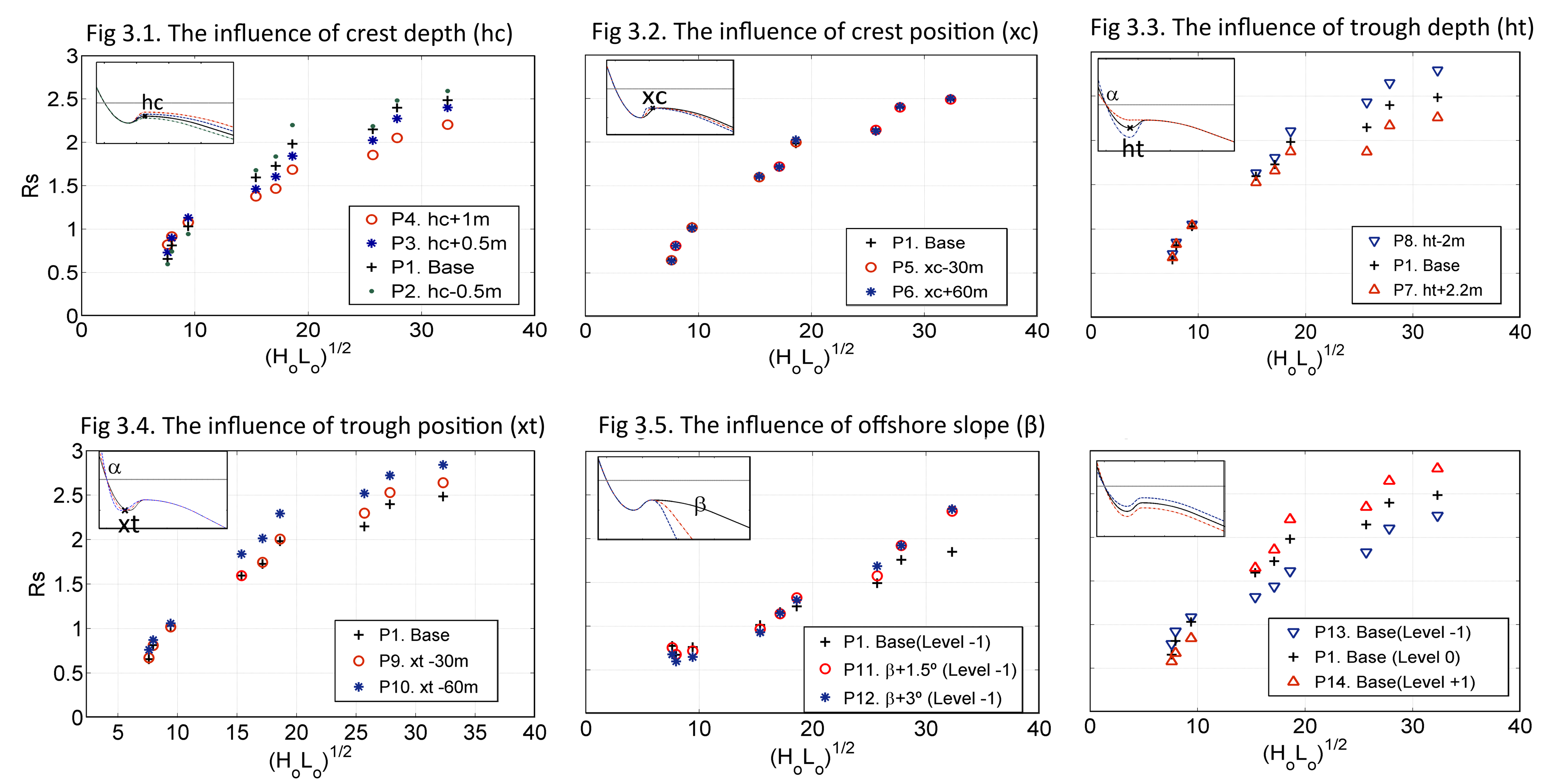
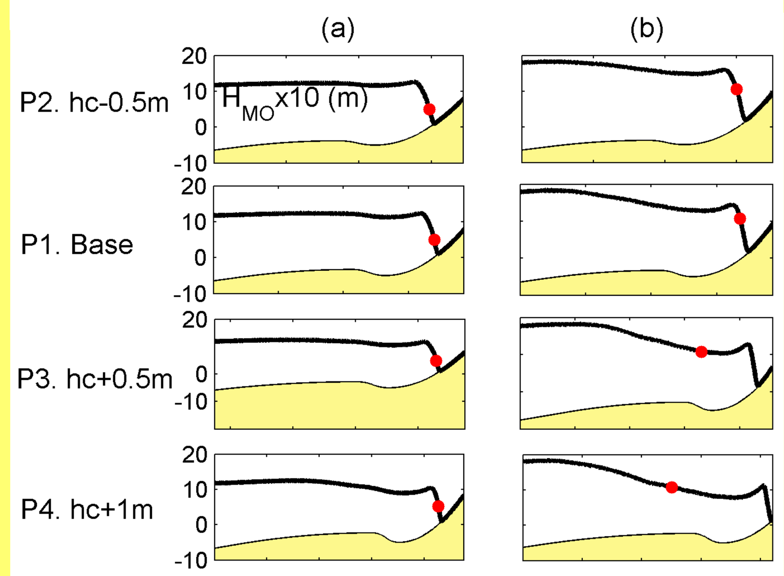


Figure 3. Significant runup as a function of incoming wave energy on barred beach profiles with changing: crest depth (Fig. 3.1), crest position (Fig 3.2), trough depth (Fig. 3.3), trough position (Fig. 3.4) offshore slope (Fig. 3.5) and tidal level (Fig. 3.6).

Discussion

- For shallower bar crest, the highest waves ($\sqrt{H_0L_0} > 10m$) break at the bar dissipating more energy and resulting in smaller R_{up}.
- In Figure 4, energetic waves (b) break at sandbar in the bathymetry P4, dissipating more energy than in bathymetry P2. However, low energetic waves (a) break by effect of onshore slope and the crest only increases the value of steepness, providing more R_{up}.
- The shallower bar troughs dissipate more energy bay friction for broken or unbroken waves, causing smaller Rup.

Figure 4. Break point and cross-shore variation of H_{MO} for barred beach profiles with changing crest depth *hc:* (a) Low energetic waves case $(H_0L_0)^{1/2}$= 7.4; (b) Energetic wave case $(H_0L_0)^{1/2}$=15.3.



- Less steep bars dissipate more energy for the more energetic waves (Fig. 5b), and thus cause smaller R_{up}, since waves find the bottom much earlier. Low energetic waves break near the highest part crest. The steeper slopes provide previous wave breaking by faster feel the seabed, higher wave dissipation (Fig. 5b), and consequently smaller R_{up}.
- The comparison between these results and the numerical runup calculated for a **uniform slope beach** with the same beachface slope (Fig. 6) shows that the simplification of the cross-shore beach profile may conduce to **overestimation of numerical R_{up} between 35 and 50%.**

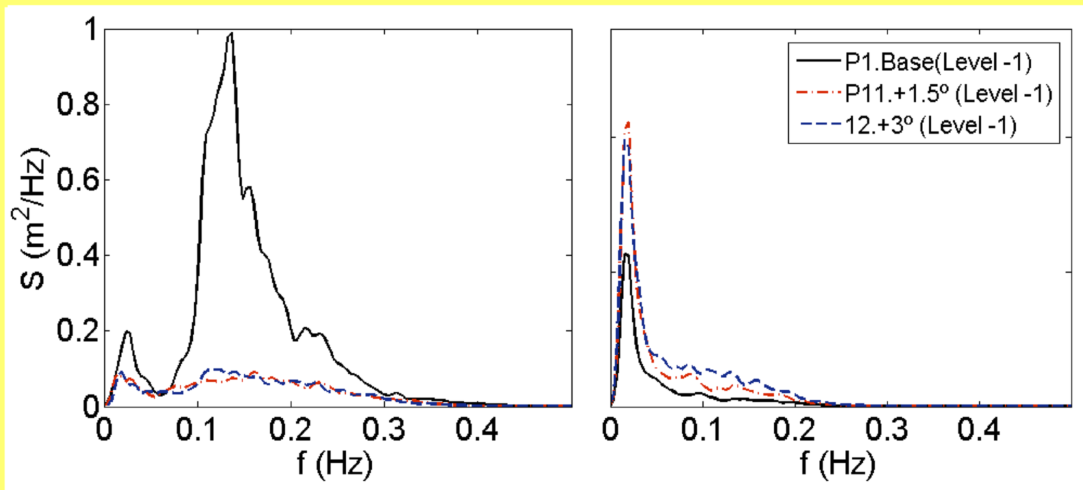


Figure 5. Energy spectra of free surface at a "gauge" located behind the bar for barred beach profiles (Fig. 2)with changing offshore slope : (a) Low energetic waves case $(H_0L_0)^{1/2}$= 7.6; (b) Energetic wave case $(H_0L_0)^{1/2}$=32.3.

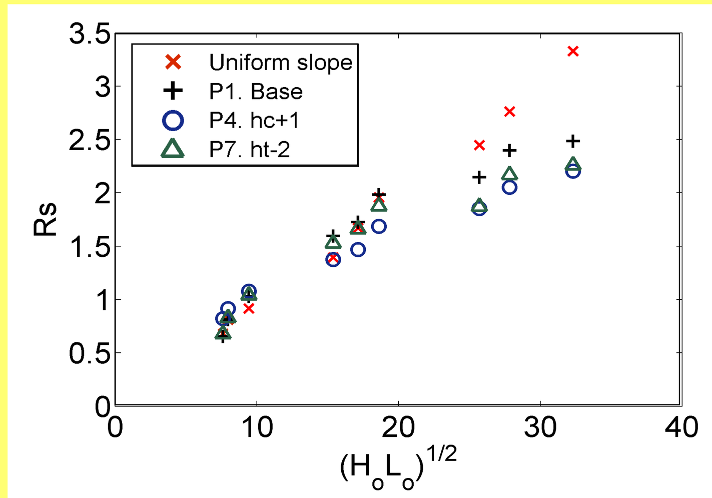


Figure 6. Significant runup as a function of incoming wave energy on a uniform slope beach and the barred beach profiles P1, P4 and P7.

Conclusions

- R_{up} over different barred beach profiles suggests a strong dependence with sandbar shape and position.
- The crest and trough depths are the geometric parameters that more affect the R_{up} since they condition the amount of energy dissipation by breaking (crest) and friction (trough).
- Shallower bar crests provide smaller R_{up} in bar broken waves. A shallower bar trough provides a smaller R_{up} in all wave cases. Accordingly low tides induce smaller R_{up} than high tides.
- Steeper face-slopes cause higher R_{up}. The runup differences caused by this parameter are lower than the ones caused by crest and trough.
- Neglecting geometric features of cross-shore beach profile might result in overestimating runup up to 50%.

BIBLIOGRAPHY

- Caballeria, M., Calvete, D., Coco, G., Dodd, N., & Falques, A. (2003), *3rd Symp. on River, Coastal and Estuarine Morphodynamics,* 310-319.
- Guedes, R.M.C., Bryan, K.R., & Coco, G. (2011), *J. Geophys. Res.,* **116.**
- Guedes, R.M.C., Bryan, K.R., & Coco, G. (2012), *Cont. Shelf Res.,* **48.**
- Longuet-Higgins, M.S., & Stewart, R.W. (1960), *J. Fluid Mech.,* **8.**
- Jalón-Rojas, I. (2013), *Master thesis.* University of Cantabria.
- Senechal, N., Coco, G., Bryant, K.R., & Holman, R.A. (2011), *J. Geophys. Res.,* **116**(53).
- Stockdon, H.F., Holman, R.A., P.A. Howd, P. A., & Sallenger, A.H. (2006) Coast. Eng., **53**, 573-588.
- Ruju, A. 2013. *Ph.D. thesis.*University of Cantabria.
- van Enckevor, I. M. J., Ruessink, B.G., Coco, G., Suzuki, K., Turner, I.L, Plant, N.G., & Holman, R.A. (2004) *J. Geophys. Res.,* **109**(C109)
- Zijlema, M., Stelling, G., & Smit, P. (2011), *Coast. Eng.,* **58**, 992-1012.

Take-home message: Wave runup depends on the vertical dimension of cross-shore profile (crest and trough depth), especially for energetic waves. Beachface slope can be an insufficient geometric descriptor of runup on real beaches.

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