Discussion of Ford, M.R.; Becker, J.M., and Merrifield, M.A. 2013. Reef Flat Wave Processes and Excavation Pits: Observations and Implications for Majuro Atoll, Marshall Islands. Journal of Coastal Research, 29(3), 545–554.

Authors: Payo, A., and Muñoz-Perez, J.J.

Source: Journal of Coastal Research, 29(5) : 1236-1242

Published By: Coastal Education and Research Foundation

URL: https://doi.org/10.2112/JCOASTRES-D-13-00051.1

Journal of Coastal Research	29	5	1236–1242	Coconut Creek, Florida	September 2013

DISCUSSION

www.cerf-jcr.org

Discussion of Ford, M.R.; Becker, J.M., and Merrifield, M.A. 2013. Reef Flat Wave Processes and Excavation Pits: Observations and Implications for Majuro Atoll, Marshall Islands. *Journal of Coastal Research*, 29(3), 545–554.

A. Payo[†] **and J.J. Muñoz-Perez**[‡*]

[†]Environmental Change Institute
University of Oxford
South Parks Road
Oxford, OX1 3QY, United Kingdom
andres.payo@ouce.ox.ac.uk

[‡]Applied Physics Department
Faculty of Sea Sciences
University of Cadiz
11510 Puerto Real, Spain
juanjose.munoz@uca.es

ABSTRACT

Payo, A. and Muñoz-Perez, J.J., 2013. Discussion of Ford, M.R.; Becker, J.M., and Merrifield, M.A., 2013. Reef flat wave processes and excavation pits: Observations and implications for Majuro Atoll, Marshall Islands. *Journal of Coastal Research,* 29(5), 1236–1242. Coconut Creek (Florida), ISSN 0749-0208.

Ford, Becker, and Merrifield observed reef flat wave conditions during two deployments over a 41 day period to investigate the impact of reef flat excavation pits on wave processes at Majuro Atoll. They noticed that the shoreline with the excavation pit received wave heights slightly less (∼8%) than those recorded at the nearby unmodified cross section. They suggested that this net decrease was the net product of a slight increase in sea and swell (SS) wave energy due to a bottom roughness reduction and a decrease in infragravity (IG) wave energy due to the disruption of the cross-shore quasi-standing modes caused by the excavation pit. We argue that, for this particular experiment, the coupling between the SS and IG energy waves may provide an alternative explanation of the observations, and we suggest that further investigations are needed. Although the coupling between SS and IG waves may be important for assessing the impact of excavation pits on IG-dominated shorelines, we show that these excavation pits in SS-dominated surf zones can lead to events such as the observed destruction of the Cadiz (SW Spain) seawall in 1792.

ADDITIONAL INDEX WORDS: *Seawall erosion, shoreline erosion, beach processes, coastal zone management*.

www.JCRonline.org

INTRODUCTION

Ford, Becker, and Merrifield (2012) observed reef flat wave conditions during two deployments over a 41 day period to investigate the impact of reef flat excavation pits on wave processes at Majuro Atoll. Experiments were conducted on two neighboring cross-shore sections of a reef flat (with claimed comparable width, topography, and incident wave energy), one modified by the excavation of a 17-m-wide, 4- to 5-m-deep pit, and the other unmodified. They observed that the shoreline with the excavation pit received wave heights slightly less (∼8%) than those recorded at the nearby unmodified cross section. The net decrease in wave energy at the shoreline was observed to be a product of a slight increase in wave energy contained in the sea and swell (SS) wave frequency band, overshadowed by a decrease in infragravity (IG) energy. They explain the slight increase in SS wave energy by a decrease in bottom roughness and the increase in IG wave energy by the disruption of the cross-shore quasi-standing modes caused by the excavation pit. They conclude that, given the range of reef flat geometries and the varying dimensions of reef flat excavation pits, further investigations are needed to assess the overall applicability of these results.

We argue that, for this particular experiment, the coupling between the SS and IG energy waves might provide an alternative explanation for the observations, and we suggest that further investigations are needed. In particular, we would like to emphasize the energy transfer from the SS waves to the IG waves within the surf zone. Figure 1 shows a conceptual model of the interactions of IG and SS wave energy. The offshore incident energy (IG or SS) could be reflected at the edge of the reef or transmitted to the reef. Because the energy

DOI: 10.2112/JCOASTRES-D-13-00051.1 received 3 March 2013; accepted in revision 19 March 2013; corrected proofs received 15 April 2013.
* Corresponding author.
Published Pre-print online 17 July 2013.

must be conserved, reflection and transmission are related (an increase in one produces a decrease in the other, shown as a negative link). The amount of reflected/transmitted waves varies with the nonlinearity of the incoming waves and the reef face geometry (Massel and Gourlay, 2000). Transmitted wave energy decreases by dissipation due to bottom friction and the breaking of waves before reaching the shoreline. The energy reaching the shoreline may be reflected backward or be further dissipated in the swash zone. Reflected waves from the shoreline may interact to either reinforce the energy at the edge (or over the reef platform) due to resonance or decrease the transmitted wave energy. IG and SS waves will have different reflection/transmission/dissipation values, and their behavior could be explained by analyzing each wave type separately, as in the analysis performed by Ford, Becker, and Merrifield (2012). However, because energy could be transferred from IG to SS and vice versa (Thomson *et al.*, 2006), the coupling between IG and SS must also be considered in the analysis of the observed data.

Based on a reanalysis of Ford, Becker, and Merrifield's (2012) observations and on comparisons with experimental observations and the modeling of wave propagation over fringing reefs of similar geometries, we suggest that the relative increase of SS wave energy and decrease of IG energy might be explained by the energy transfer from SS waves to IG waves. First, the experimental observations of Ford, Becker, and Merrifield (2012) are compared with the experimental results presented by Massel and Gourlay (2000). It is estimated that wave breaking, not wave energy dissipation due to bed roughness, is the dominant process for the geometry and wave conditions at Majuro Atoll. This finding suggests that the increase in water depth at the pit excavation (*i.e.* hindering the breaking of shorter waves) is more important than the reduction of bed roughness felt by the breaking waves. Second, we reanalyze Ford, Becker, and Merrifield's (2012) experimental data and suggest that most of the IG wave energy is due to bond waves, nonlinearly driven by groups of swells and liberated in the surf zone by the breaking of SS waves. The relative increase (decrease) in IG energy at the unmodified (excavated) profile is then explained by an increase (decrease) in energy transfer from SS to IG waves rather than by the dissipation of existing IG energy. Although this energy transfer might be important for shorelines dominated by IG waves, we show that the excavation of the reef might have catastrophic consequences for SS-dominated shorelines. One possible example of such an outcome is the failure of the seawall of the city of Cadiz (SW Spain) in 1792. This failure appears to have been a consequence of reef excavation (Muñoz-Perez *et al.*, 2009).

CONTRIBUTION OF BREAKING AND FRICTION TO ENERGY DISSIPATION

The data of Ford, Becker, and Merrifield (2012) indicate that waves were breaking all over the platform (*i.e.* SS wave height was tidally modulated) and that, therefore, both dissipation mechanisms, breaking and bottom friction, were active along the whole width of the platform. Ford, Becker, and Merrifield (2012) suggest that a decrease in bed roughness (due to an increase in depth at the excavation pit) might explain the relative increase in SS waves at the shoreward area of the pit. Although this suggestion may well be correct, they did not provide an estimate of the relative dissipation rates resulting from breaking and bottom friction. If dissipation due to breaking is more important, minor changes in water depth (*i.e.* an increase in depth reduces the percentage of breaking waves) are more likely than bottom friction to explain the slight relative increase in SS waves.

An estimate of the relative importance of breaking and bottom friction can be obtained from the experimental and modeling results presented by Massel and Gourlay (2000). Massel and Gourlay (2000) proposed the addition of an empirical parameter, α, to include the effect of the reef-face slope, β, on energy dissipation due to breaking, and they included the parameter α in the refraction diffraction equation (Massel, 1993) used to predict wave height attenuation and wave setup. The results from the modified equation compared well with the experimental data. This empirical parameter correlates well with the dimensionless nonlinearity parameter, F_{C0},

$$F_{C0} = \frac{g^{1.25} H_0^{0.5} T^{2.5}}{h_r^{1.75}},$$

where H_0 is the offshore wave height, h_r is a representative depth over the profile, T is the peak period, and g is the acceleration of gravity (Gourlay, 1994). For the overwash event of 29 June 2011, $H_0 = 2$ m, $T = 13$ s, and $h_r = 0.7$ m at the unmodified profile, giving a value of $F_{C0} \sim 2700$. The reef geometry at Majuro Atoll is similar to the geometry of the Hayman Island reef (*i.e.* $\beta \sim 1:4.5$ and approximately constant depth over the reef flat). For the Hayman Island reef, Massel and Gourlay (2000) found that waves plunge over the reef edge and dissipate almost all their energy within five wave lengths if $160 < F_{C0} < 530$. Assuming that we can extrapolate the fitted values for Hayman Island (see Equation 1) to the value of F_{C0} for Majuro Atoll at the peak of the overwash event, the empirical α is equal to 5.66.

$$\alpha = 0.0156(F_{C0} - 100)^{0.576} \qquad \text{if } F_{C0} > 100. \tag{1}$$

The empirical coefficient is proportional to the average rate of energy dissipation per unit of area due to breaking, $\langle \varepsilon_b \rangle$:

$$\langle \epsilon_b \rangle = \frac{\alpha \rho g \omega}{8\pi} \frac{\sqrt{gh}}{C} \frac{H^3}{h}, \tag{2}$$

where ρ is the water density (1028 kg/m^3), ω is the wave frequency, C is the phase wave velocity, h is the water depth, and H is the wave height. The average rate of energy dissipation per unit of area due to bottom friction, $\langle \epsilon_f \rangle$, is

$$\langle \epsilon_f \rangle = \frac{2}{3\pi} \rho f_r |u_b|^3, \tag{3}$$

where f_r is the friction coefficient, and u_b is the bottom orbital velocity. To obtain an order-of-magnitude estimate of each dissipation rate, we assumed that $f_r = 0.2$ (Nelson, 1996), and

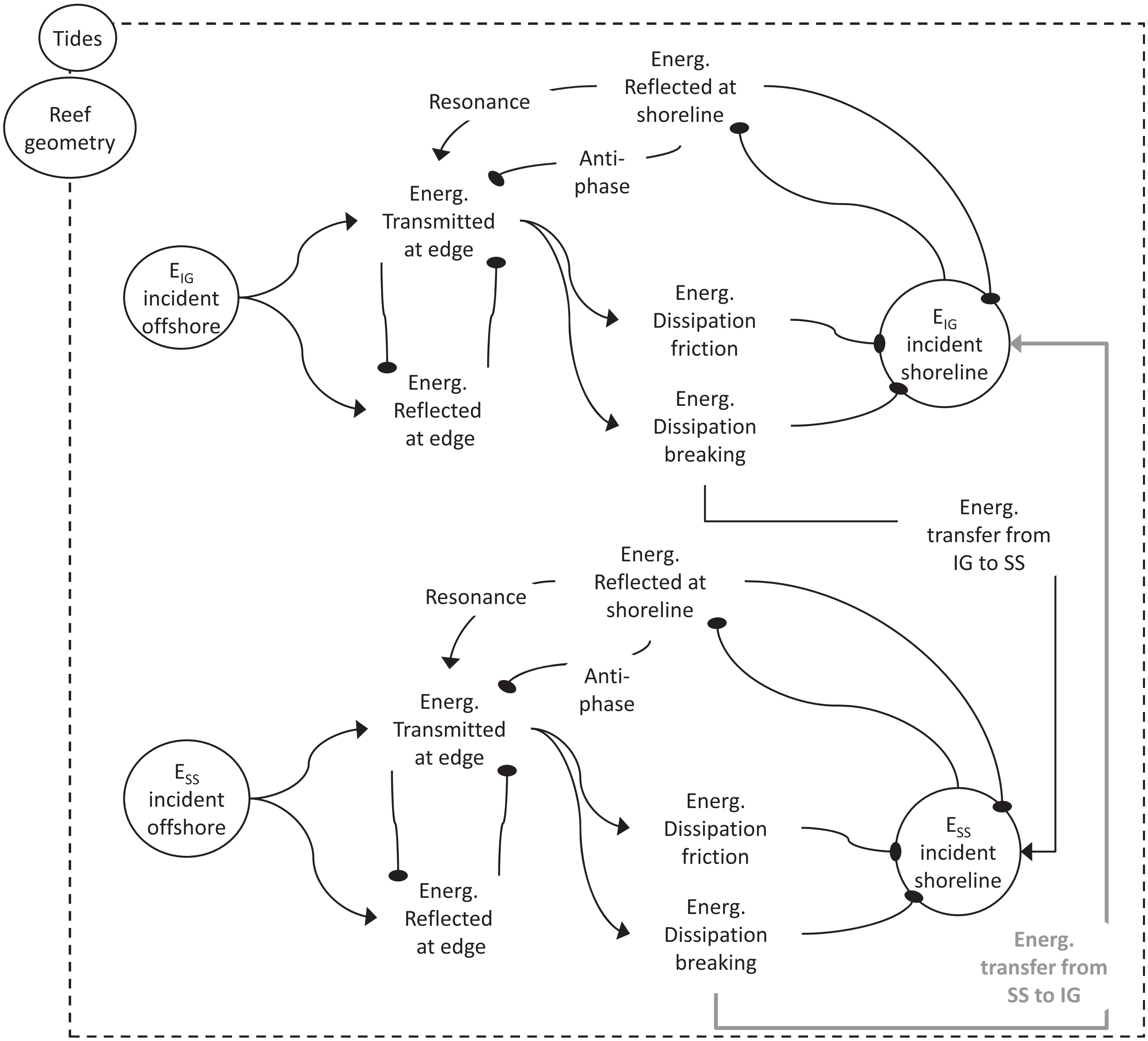

Figure 1. Causal loop diagram showing the links (positive = line with arrowhead, negative = line with circle) between the main processes (plain text) and state variables (bubble text) that control the energy transfer from offshore to the shoreline. The geometry of the reef (including excavation pits) and tides influence the magnitude of the processes. We argue that the energy transfer from SS to IG waves might also effectively explain the observed experimental results.

we estimated the orbital bottom velocity ($u_b = 1.24$ m/s), phase velocity ($C = 3.12$), and wave height at breaking ($H = 0.8$ m) based on the dispersion relationship for progressive linear water waves and Snell's law for straight and parallel offshore contours at $h = 1$ m (Dean and Dalrymple, 1984). Note that linear wave theory is not valid near the reef edge due to an abrupt depth change, but it will be indicative to within an order of magnitude well within the surf zone. The ratio between the resulting average rate of energy dissipation per unit of area due to breaking and bottom friction is $\langle\epsilon_b\rangle/\langle\epsilon_f\rangle = 563/83 \sim 7$. This value could be considered a lower limit because the friction factor was assumed to be equal to the high values observed on coral reefs.

It can be concluded that during the peak of the overwash event at Majuro Atoll, waves were plunging at the edge of the reef, and the average energy dissipation due to breaking was at least seven times higher than the energy dissipation due to bottom friction. The width of the reef (~100 m) is relatively

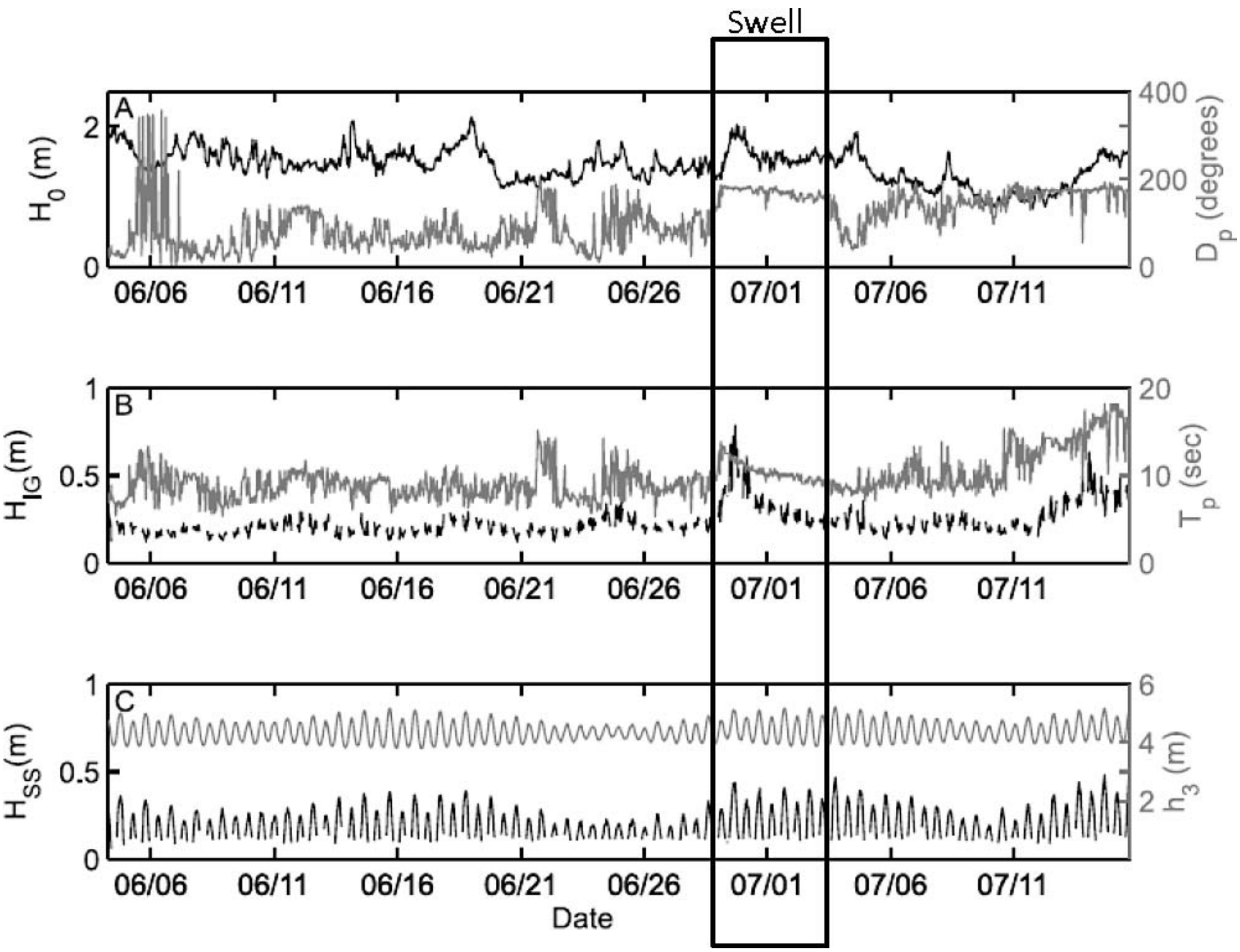

Figure 2. The event of 29 June 2011 shows properties of swell waves, such as constant direction and decreasing wave period, for the duration of the event. A strong correlation between IG wave energy and swell energy is consistent with the theory of bound waves. If the square of the buoy energy correlates well with the IG wave energy, this result would suggest that for Majuro Atoll, IG is generated primarily by SS breaking (modified from Ford, Becker, and Merrifield, 2012, Figure 4).

limited, approximately three times the wave length of the SS, suggesting that energy transfer from SS waves to IG waves may occur throughout the reef.

BOUND WAVES VERSUS FREE LONG WAVES

Ford, Becker, and Merrifield (2012) suggest that the decrease in IG wave energy shoreward of the excavated profile was due to the modification of the standing mode of the IG waves. By reanalyzing their experimental data, we found evidence that the IG energy may also be due to bound waves nonlinearly driven by groups of swells rather than to free waves. Because bound waves are liberated at the surf zone by breaking waves, this finding may also explain the observed experimental data.

We argue that most of the IG wave energy is associated with wave energy transfer from SS waves due to intensive breaking over the reef-flat edge, not with free-traveling long waves. From the offshore data available (wave buoy), it is not possible to identify the presence of long waves offshore due to instrument limitations in capturing waves longer than 30 s. Figure 2 (from Ford, Becker, and Merrifield, 2012, Figure 4) shows that for the overwash event, the incoming waves were nearly shore normal, and the peak period decreased over time (*i.e*. the faster waves arrived first). The relatively constant direction during the event suggests that it was due primarily to swell waves (rather than to sea waves with higher directional spreading and frequency). Therefore, the wave energy recorded at the buoy can generally be considered to represent swell energy waves. If infragravity motion is due to bound waves,

Table 1. *Theoretical amplification ratios (R) for bound and free waves and observed values from Ford, Becker, and Merrifield's (2012) Figure 7B.*

Stations	Depth Ratio	R Theoretical Bound Waves (h^{-5})	R Theoretical Free Waves ($h^{-1/2}$)	Observed
IG_2/ IG_4	0.9/1.0	~1.7	~1.05	~1.5
IG_1/ IG_4	0.85/1.0	~2.25	~1.12	~2

then the IG wave energy is proportional to the square of the swell energy (Elgar *et al*., 1992). Unfortunately, the correlation between offshore wave energy and IG wave energy was not computed to verify this expectation, and this relationship may not hold for steep slopes such as that of Majuro Atoll.

The theoretical ratio, R, between the IG wave energy values for stations 1, 2, and 4 (IG_1, IG_2, IG_4) is of the order of magnitude expected for bounded waves. Neglecting alongshore depth variations, the bound wave energy forced by unidirectional, normally incident long waves is proportional to h^{-5}, whereas the bound wave energy is proportional to $h^{-1/2}$ for the amplification of free (leaky) surface gravity waves in shallow water (references in Elgar *et al*., 1992). Table 1 shows the theoretical estimated R values and the R values derived from Ford, Becker, and Merrifield's (2012) Figure 7B. The depth ratios were obtained visually from their Figure 2B, and the observed values are from their Figure 7B. These values could be considered approximate, but estimates accurate to one order of magnitude suggest that the observed amplification may well correspond to bounded waves. The relative increase (decrease) in the IG wave energy at the unmodified (excavated) profile could be explained by a higher (lower) amount of energy transfer due to higher (lower) dissipation of SS waves as a result of breaking at the unmodified (excavated) profile.

Ford, Becker, and Merrifield (2012) assume that the two cross sections have comparable incident wave energy. However, their Figure 8 (C and D) shows that the maximum significant wave height during the overwash event of 29 June 2011 was 1.22 times higher at station 6 than at station 3. Ford, Becker, and Merrifield (2012) state that the wave height at station 3 (within the excavated pit) was most likely biased low, because linear wave theory, used to obtain the sea-surface elevation from the pressure sensor, is most likely invalid for SS waves due to the abrupt depth changes and the limited extent of the excavated pit but is valid for IG waves (after minor corrections). Although this assertion may be correct, Ford, Becker, and Merrifield (2012) do not provide an estimate of the bias (*i.e*. after this bias is corrected, do the wave heights at stations 3 and 6 correlate 1:1?). We argue that this bias explains only a minor fraction of the observed 22% deviation, at least for the wave periods >10 s, where most of the SS wave energy is concentrated (see Ford, Becker, and Merrifield, 2012, Figure 10). This argument suggests that the wave energy at the edge of the unmodified transect is higher than that at the excavated profile. Due to the nonlinear transfer between swell waves and IG bounded waves, small changes in the incident swell energy may produce substantial changes in the IG wave energy content.

Ford, Becker, and Merrifield's (2013) Figure 2 shows how the beach face of the unmodified profile (C) has a milder slope than the profile with the excavation pit (B). This characteristic could be consistent, ceteris paribus (*i.e*. given the same sand size), with the lower level of energy. Nevertheless, the statement of the authors that "no noticeable change in shoreline wave heights is observed … suggesting that the reflected wave energy is similar for both transects" is not exactly consistent with the wave data presented in their Figure 8. Therefore, the greater reflection of the waves associated with the steeper face (Bernabeu, Medina, and Vidal, 2003) and its possible effect on the slight increase/decrease of the wave height should be evaluated as well. Moreover, changes in the beach profiles should be discussed because the results could yield information about the influence of the tidal levels in addition to the different levels of wave energy. For example, Muñoz-Perez and Medina (2000) demonstrated a relationship between profile variability at a reef-protected beach and the fortnightly variation of the tidal range, and a preliminary conceptual model was presented based on the RTR parameter defined by Masselink and Short (1993). Moreover, experimentally demonstrated changes in reef-protected profiles just after a storm, as well as the immediate recovery process, can be considered (Muñoz-Perez and Medina, 2005).

IMPLICATIONS FOR COASTAL MANAGEMENT

We have suggested that for the Majuro Atoll experiment, where shoreline wave energy is dominated by the IG waves (see Ford, Becker, and Merrifield, 2012, Figure 10), the presence of a pit might reduce the IG energy due to energy transfer from SS to IG. However, we would like to emphasize that excavation pits might have catastrophic effects.

We believe such was the case for the failure in 1792 of the Cadiz seawall. Following the sacking of Cadiz (SW Spain) by an English and Dutch fleet in 1596, the inhabitants sought to raise the city walls as protection against further assaults. After two centuries, the southern front, with a 700-m-wide seaward reef flat emerging at low tide, had yet to be completed. To lower the cost of construction of this stretch of wall, also known as "del Vendaval," or the gale front, the nearby reef was excavated as a source of armor stone, and the wall was eventually finished in 1791 (Muñoz-Perez *et al*., 2009). The excavation was located all along the seawall front (approximately 900 m long), ranging in width from 100 m to 300 m and in depth from 1 to 3 m. Regrettably, this impressive work was destroyed by the sea only a year later. The wave energy at the toe of the seawall was increased due to the excavation of the reef flat and the resulting decrease in the dissipation of wave-breaking energy. While the IG wave might also have decreased due to decreased energy transfer from SS waves, the net balance was an increase in SS waves. It is probable that the relatively small waves breaking over the reef before the excavation broke over the seawall foot and eroded it. Thus, although Ford, Becker, and Merrifield are very cautious when they suggest that "for the conditions observed during the experimental period, design criteria for the construction of coastal protection do not need to be strengthened to account for additional wave energy at the shoreline," it is to be hoped that this statement will not be invoked to justify an increase in the number of infrastructure projects involving land reclamation.

Although we understand the concern of the people of Majuro Island regarding the regression of their shoreline (for a model of this type of cliff shoreline erosion, see Gomez-Pina *et al.*, 2012), the substitution of "hard" techniques (such as armor stone) for other "soft" techniques (such as beach nourishment) should at least be studied (Gomez-Pina *et al.*, 2006). "Soft" techniques are especially attractive because it has been demonstrated that dredging and sand discharge activities result in minimal effects on water quality (Roman-Sierra *et al.*, 2011).

Nevertheless, those who might seek to establish claims to land in the shore areas of current concern should consider that, most likely, no equilibrium beach profile is possible within a distance of less than 10 to 30 h_r from the edge of the reef, where h_r is the water depth over the reef (Bernabeu, Muñoz-Perez, and Medina, 2002; Muñoz-Perez, Tejedor, and Medina, 1999).

Obviously, the easiest and least expensive solution is to make decisions during the design phase to locate urbanization and infrastructure projects farther from the coastline. For this reason, the Spanish Shore Act (1988) imposed a protection easement on a zone extending 100 m landward from the limit of the seashore. Any activity involving construction is forbidden in these areas. Moreover, bathymetric levelings and studies of biological and littoral dynamics are mandatory before the initiation of any type of public or private work close to the seashore. If urban decisions are made in recognition of the importance of leaving sufficient unoccupied space to accommodate the sea and its natural variability, many problems could be avoided. However, we do not claim the right to mandate a solution. After 25 years of attempts, it is still hoped that integrated coastal zone management will soon be established in Spain (Barragan, 2003).

CONCLUSIONS

Based on Massel and Gourlay (2000), we estimated that waves were plunging at the reef edge and flooding the entire platform during the peak of the event on 29 June 2011 at Majuro Atoll. The energy dissipated due to wave breaking is estimated to be at least 7 times higher than the energy dissipated due to bottom friction. This result suggests that minor changes in wave breaking are more likely to explain the relatively higher SS wave energy at the landward side of the excavation profile (*i.e.* dissipation due to breaking at the pit is less than that over the unmodified profile due to a smaller percentage of waves actually breaking). The data we examined suggest that the IG wave energy is related to bound waves that are generated during the breaking of swell waves over the platform. The relatively narrow width of the platform (approximately three times the wave length of breaking waves) suggests that energy transfer from SS waves to IG waves occurs throughout the width of the platform. The excavation pit partially hinders the breaking of, and therefore the transfer of energy to, the IG waves. The SS wave height, approximately 1.22 times higher at station 6 than at station 3, suggests that the southerly wave event was not completely shore normal and that a certain amount of wave refraction (in addition to the downward-biased estimate of the surface elevation from the pressure sensor and linear theory) may explain the relatively higher incident wave energy in the unmodified profile. Higher-incident waves may imply higher IG waves, rendering the influence of the small excavated profile less significant for this particular event. We emphasize that excavation pits may reduce the energy at the shoreline for an IG-dominated surf zone but can have catastrophic effects, such as the complete destruction of the "Vendaval" Cadiz seawall in 1792, on surf zones dominated by SS.

LITERATURE CITED

Barragan, J.M., 2003. Coastal zone management in Spain (1975–2000). *Journal of Coastal Research*, 19(2), 314–325.

Bernabeu, A.M.; Medina, R., and Vidal, C., 2003. Wave reflection on natural beaches: an equilibrium beach profile model. *Estuarine, Coastal and Shelf Science*, 57(4), 577–585.

Bernabeu, A.M.; Muñoz-Perez, J.J., and Medina, R., 2002. Influence of a rocky platform in the profile morphology: Victoria Beach, Cádiz (Spain). *Ciencias Marinas*, 28(2), 181–192.

Dean, R.G. and R. Dalrymple, 1984. *Water Wave Mechanics for Engineers and Scientists*. Singapore: World Scientific, 371p.

Elgar, S.; Herbers, T.H.C.; Okihiro, M.; Oltman-Shay, J., and Guza R.T., 1992. Observations of infragravity waves. *Journal of Geophysical Research*, 97(C10), 15573–15577. doi:10.1029/92JC01316

Ford, M.R.; Becker, J.M., and Merrifield, M.A., 2013. Reef Flat Wave Processes and Excavation Pits: Observations and Implications for Majuro Atoll, Marshall Islands. *Journal of Coastal Research,* 29(3), 545–554.

Gomez-Pina, G.; Fages, L.; Ramirez, J.L.; Muñoz-Perez, J.J., and Enriquez, J., 2006. A critical review of beach restoration projects in the northern coast of Cadiz (Spain) after thirteen years. *Coastal Engineering Proceedings*, 1(30), 4167–4178. doi:10.1142 / 9789812709554_0350

Gomez-Pina, G.; Muñoz-Perez, J.J.; Figueres, M.; Garrido, J.M.; Ponce de Leon, D.; Perez, A.; Velasco, M., and Lizondo, S., 2012. Study of cliff shoreline erosion. *Coastal Engineering Proceedings*, 1(33). doi:10.9753/icce.v33.sediment.96

Gourlay, M.R., 1994. Wave transformation on a coral reef. *Coastal Engineering*, 23(1–2), 17–42.

Massel, S.R., 1993. Extended refraction–diffraction equation for surface waves. *Coastal Engineering*, 19(5), 97–126.

Massel, S.R. and Gourlay, M.R., 2000. On the modelling of wave breaking and set-up on coral reefs. *Coastal Engineering*, 39(1), 1–27.

Masselink, G. and Short, A.D., 1993. The effect of tide range on beach morphodynamics and morphology: a conceptual beach model. *Journal of Coastal Research*, 9(3), 785–800.

Muñoz-Perez, J.J.; Fages, L.; de la Casa, A., and Gomez Pina, G., 2009. The Cadiz city walls and their battle against the sea. *Revista de Obras Publicas*, 3495, 41–52.

Muñoz-Perez, J.J. and Medina, R., 2000. Profile changes due to a fortnightly tidal cycle. Coastal Engineering 2000, 3062–3075. doi:10.1061/40549(276)238

Muñoz-Perez, J.J. and Medina, R., 2005. Short term variability of reef protected beach profiles: an analysis using EOF. *In: 5th Interna-*

tional Conference on Coastal Dynamics (Barcelona, American Society of Civil Engineers). doi:10.1061/40855(214)2, pp. 1–11.

Muñoz-Perez, J.J.; Tejedor, L., and Medina, R., 1999. Equilibrium beach profile model for reef-protected beaches. *Journal of Coastal Research*, 15(4), 950–957.

Nelson, R.C., 1996. Hydraulic roughness of coral reef platforms. *Applied Ocean Research*, 18(5), 265–274.

Roman-Sierra, J.; Navarro, M.; Muñoz-Perez, J., and Gomez-Pina, G., 2011. Turbidity and other effects resulting from Trafalgar sandbank dredging and Palmar beach nourishment. *Journal of Waterway, Port, Coastal, and Ocean Engineering*, 137(6), 332–343. doi:10.1061/(ASCE)WW.1943–5460.0000098

Spanish Shore Act, 1988. BOE no. 181, 29 July 1988.

Thomson, J.; Elgar, S.; Raubenheimer, B.; Herbers, T.H.C., and Guza R.T., 2006. Tidal modulation of infragravity waves via nonlinear energy losses in the surfzone. *Geophysical Research Letters*, 33(5), L05601. doi:10.1029/2005GL025514