PHYSICAL MODEL AND REVISION OF THEORETICAL RUNUP

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Several formulations deduced from empirical studies are available for runup estimation. Scattering is high when applied to practical cases. Through a state of the art best formulations are chosen. These equations are also studied in a physical model carried out in the Laboratory for Maritime Experimentation of CEDEX with three beaches with slopes 1/20, 1/30 and 1/50 and with sand bed. The performance of each formulation is discussed. A new formulation is proposed in order to give more weight to the beach slope thus reducing scatter.

Keywords: runup, swash, setup, beach processes

INTRODUCTION

The extreme phenomena due to the climate change have recovered the interest in the determination of the runup in beaches. Runup quantification is essential in coastal management and protection against coastal flooding. This study comprises a revision of the state of the art in the runup research and an experimental work based on a 2D physical model with mobile bed. Results will help to improve the knowledge of runup processes, with the aim of choosing the best formulations available for coastal engineering applications and a proposal to improve runup prediction.

LITERATURE REVIEW

The runup was studied from different approaches such as theoretical, spectral or statistical. Two first mentioned methods have been useful to describe the morphodynamic that influences the assessment of runup such as: the beach state, reflective or dissipative, (Kiyoshi Horikawa, 1988), turbulence in the swash (Longo, 2002), etc. The complexity in the hydrodynamic processes within the surf zone and its interaction with beach morphology make hard to develop numerical models for resolving applicable equations (Kobayashi, 1997). Hence statistical studies are still, nowadays, the better choice in the estimation of this parameter for coastal management applications.

For a statistic methodology two kind of experiments have been carried out: physical models and field testing. First physical models started with runup assessment in structures with regular wave (Miche, 1951; Iribarren and Nogales, 1949), and a first formulation that related runup with Iribarren number ξ was set (Hunt, 1959). Van Oorshot and D'Angremont (1968) developed first experiment with irregular wave, the study addressed the influence of spectral width wave. The experiments had still strong slopes in relation with beaches, Battjes (1974) studied milder slopes and established a Iribarren number range for the application of the formulations. Van Dorn (1976) made first work exclusively focused on beaches; it was from this study when runup analysis on beaches was separated of runup on structures.

The following studies made experiments in field and in laboratory yielding several equations for the estimation of the parameter R_2 expressed as the 2% exceedence value of runup maxima. The methodology frequently used for estimation of R_2 is the “Peak method” (Douglass, 1990). The formulations developed from experiments for runup assessment can be grouped in two: R_2-ξ_{0p} (1) and R_2-$H_{m0}L_0$ (2) (see below). It must be noticed both equations can be related each other. A summary of different formulations is presented, Table 1.

$$\frac{R_2}{H_{m0}} = K_1 \cdot \xi_{op} \tag{1}$$

$$R_2 = K_2 \cdot (H_{m0}L_0)^{0.5} \tag{2}$$

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Table 1.- Formulations available for runup estimation on beaches

Reference	Experiment Features			Equation
	Kind	Seabed	Slope "m"	
Van Dorn (1976)	Physical model Regular Wave	Fix	0.002 to 0.083	R_2-ξ_{0p}
Guza and Thornton (1982)	Field Testing	Sand	0.03 to 0.051	R_2-ξ_{0p}
Mase and Iwagaki (1984)	Physical model Random Wave	Fix	1/5, 1/10, 1/20, 1/30	R_2-ξ_{0p}
Channel et al. (1985)	Field Testing	Gravels	1/6, 1/10	R_2-ξ_{0p}
Holman (1986)	Field Testing	Sand	0.07 to 0.2	R_2-ξ_{0p}
Resio (1987)	Field Testing	Sand	0.07 to 0.2	R_2-ξ_{0p}
Van der Meer (1988)	Physical model Random Wave	Fix	1/1.5, 1/3, 1/5	*Other*
Mase (1989)	Physical model Random Wave	Fix	1/5 to1/30	R_2-ξ_{0p}
Douglass et al. (1990)	Field Testing	Sand	0.07 to 0.2	R_2-ξ_{0p}
Nielsen and Hanslow (1991)	Field Testing	Sand	1/5 to 1/30	R_2-$H_{m0}L_0$
Ahrens and Seeling (1996)	Field Testing	Sand	---	R_2-ξ_{0p}
Ruggiero et al. (2001)	Field Testing	Sand	1/20 to 1/30	R_2-$H_{m0}L_0$
Hedges and Mase (2004)	Physical model + Field Testing	Fix and Sand	1/5, 1/10, 1/20, 1/30	R_2-ξ_{0p}
Stockdon et al. (2006)	Field Testing	Sand	1/50 to 1/9	R_2-$H_{m0}L_0$

Formulation performance comparison

In order to evaluate the performance of the forecast with those formulations, R_2 is calculated with data from a real storm occurred in Spain in S'Abanell Blanes beach the November 11th 2001. The data collected was: Significant height of 4.6 m, peak period of 13.6 s, foreshore slope 1/30, Figure 1.

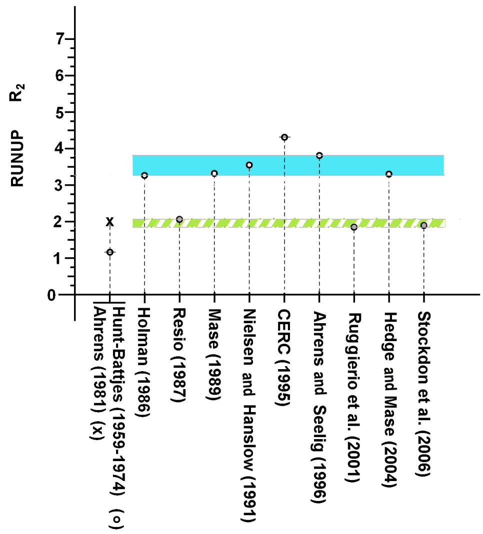

Figure 1. Comparison of performance for the main formulations in the runup assessment. Two areas of performance, solid and dashed shadow, that define trends within an error threshold less than 15%.

Two performance areas are considered, one of them is defined by Holman (1986), Mase (1989), Nielsen and Hanslow (1991), Ahrens and Seeling (1996) and Hedges and Mase (2004), the other area is described by Resio(1987), Ruggierio et al. (2001) and Sotckdon et al. (2006), in each of them the prediction is obtained within an error threshold less than 15%, data out of these areas are not considered.

EXPERIMENTAL STUDY

Runup has been studied from physical models trying to isolate some of the processes involve in the swash so avoid dynamics that are hard to record such as surf beat or edge waves. Usually those models were designed with fixed seabed what involve the assumption of two main conditions: rigid morphology, independent from the time, what inhibits the profile evolution that influences in the breaking process; and material rugosity that could be differ from sand, and could affect the up-rash and down-rash giving error in values. For these reasons it was proposed a physical model with mobile bed with the aim of evaluating the influence of the assumption of fix seabed in formulations for predicting R_2 and seeking improvements in the estimation.

Physical model

A physical model was built in the Laboratory for Maritime Experimentation, Centre for Harbous and Coastal Studies of CEDEX, Madrid. The model was set up in a wave flume 36.5 metres long, 6.5 metres wide and 1.3 metres deep (Figure 2) equipped with a piston-type wave generator device, it is able to yield both, regular and random waves. The model is considered with scale 1:20 to design offshore wave conditions. To compare the performance on a different sand diameters, the flume was divided in two parts, one of those zones was filled with sand of a grain size (Hereinafter D_{50}) of 0.12 mm and the other with sand D_{50} of 0.70 mm. Three modeled beaches were studied with different initial foreshore slopes: 1/50 (dissipative), 1/30 (intermediate) and 1/20 (reflective).

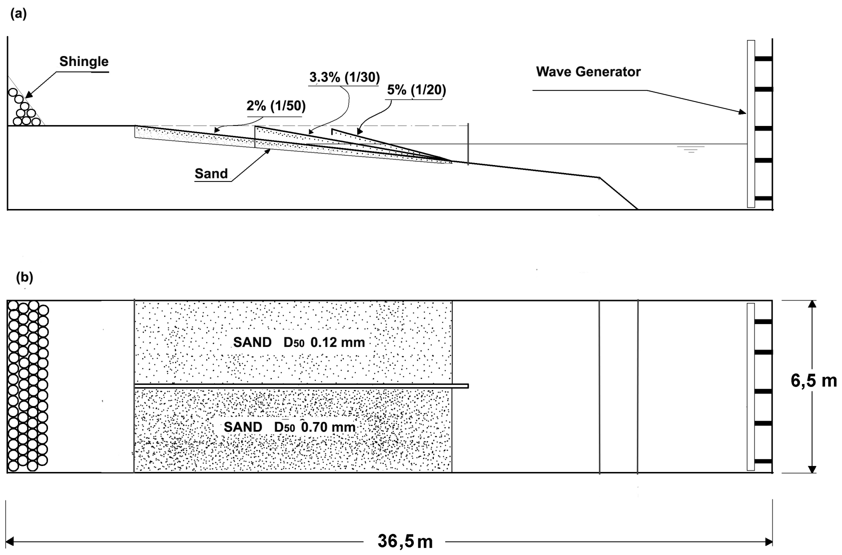

Figure 2. Scheme of the Physical Model. Wave flume Laboratory for Maritime Experimentation, CEDEX.(a) longitudinal section (b) plan view.

Measures of the waves and the swash motion were obtained with capacity gauges. Waves were measured by 3 gauges for each sand, close to the wave generator. In the case of swash motion at the shore, it was designed a gauge 6 m long, arranged parallel to the slope in both diameters 1 cm high. To remain them hanging parallel to the slope, it was used a structure similar to a suspension bridge.

Test Conditions

For each foreshore slope it was generated several sea states so the Iribarren number threshold was between 0.1 to 0.6. With this condition the range for significant wave height was 0.5 m to 4 m and the peak period varied between 4 and 14 s, Table 2. It was planned approximately 200 waves in every state what involve 200 to 650 s of measure dependent in the peak period of each case. Froude similitude was chosen so that the associated scale effects herein could be neglected , it was assumed that viscous effects are balanced by surface tension effects in the gauges.

Table 2- Experimental data program

Slope	1/50			1/30			1/20		
H_{m0} (m)	Test	T_p (s)	ξ_{0p}	Test	T_p (s)	ξ_{0p}	Test	T_p (s)	ξ_{0p}
0.5							200505	5	0.44
							200506	6	0.53
1.0	501004	4	0.10	301004	4	0.17	201004	4	0.25
	501008	8	0.20				201006	6	0.37
	501012	12	0.30	301007	7	0.29	201008	8	0.50
1.5	501506	6	0.12	301505	5	0.17	201505	5	0.25
	501508	8	0.16	301506	6	0.20	201508	8	0.41
	501512	12	0.24	301508	8	0.27	201510	10	0.51
				301509	9	0.31			
2.0	502005	5	0.09	302005	5	0.15	202006	6	0.27
	502010	10	0.18	302007	7	0.21	202009	9	0.40
	502012	12	0.21	302009	9	0.27	202011	11	0.49
				302010	10	0.29			
				302012	12	0.35			
2.5	502508	8	0.13	302508	8	0.21	202507	7	0.28
	502510	10	0.16	302510	10	0.26	202510	10	0.39
	502512	12	0.19	302511	11	0.29	202512	12	0.47
				302512	12	0.32			
3	503007	7	0.10	303007	7	0.17	203008	8	0.29
	503014	14	0.20	303010	10	0.24			
				303012	12	0.29			
3.5				303509	9	0.20			
				303513	13	0.29			
4				304008	8	0.17			
				304014	14	0.29			

RESULTS

Data treatment

The data processing showed the influence of a long wave in the flume that could distort the results. For this reason the long wave was filtered through the process referenced bellow. In the signal of the wave spectra the long wave was detected at frequency approximately equal to 0.03 Hz, another long oscillation was detected at 0.055 Hz what could be correspond with a second order mode. Third order mode could not be detected, hence, from the second order, it was considered the upper modes negligible. To corroborate if the long wave is presented in the runup, it was studied the runup spectra were a peak in low frequencies were detected too. The steps followed for the filter were: Identification of the frequencies which were energy from long wave; taking out the waves from these frequencies from the wave and runup signal; test correlation between long wave in runup and wave signal, if the correlation is high the long wave is eliminated from the spectra and the final data is obtained, Figure 3.

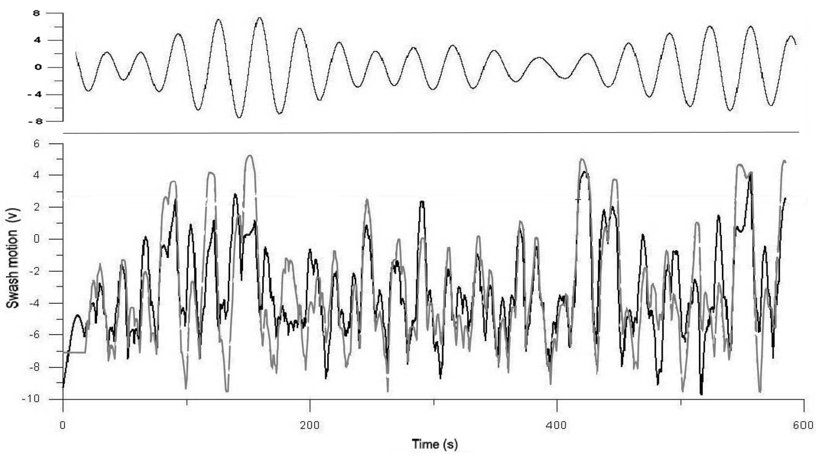

Figure 3.- Comparison between swash signal with and without long wave (dashed and solid line respectively) in one of the cases. The long wave associated is included above the graph to clear the filter process.–

Runup Estimation

Swash motion signals filtered were treated to calculated the statistic parameter R_2 through the methodology named “peak method” (Douglass, 1990). Once the peaks were obtained, the peaks under the still water level (SWL) were eliminated. The determination of R_2 were approached by two methodology: direct estimation with sample and fit a probabilistic distribution Function (PDF). It was chosen a Normal PDF which is accurate enough (Hughes et al., 2010). However the Normal PDF underestimated extreme values of the sample, hence it was chosen a direct assessment as a better estimation of R_2.

R_2 was obtained for each case in both grain sizes. Results are compared in Figure 4. For slopes 1/50 and 1/20 the runup is quite similar but in the case of slope 1/30 there is a different behaviour that could be related with problems in the runup wire.

As a first approach relative runup R_2/H_{m0} results were compared with Iribarren number (Figure 6). As expected there is a fair relation between both variables and the runup value increases with the value of Irribarren number.

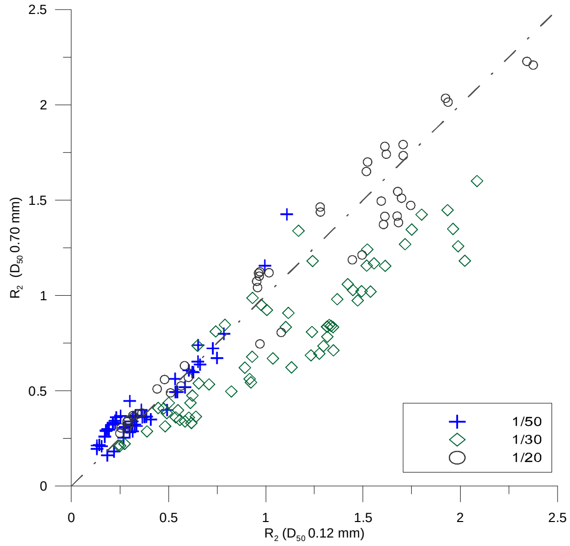

Figure 4.- Runup, R_2, depending on sand diameter (D_{50}) grouped by slopes. Units in meters.

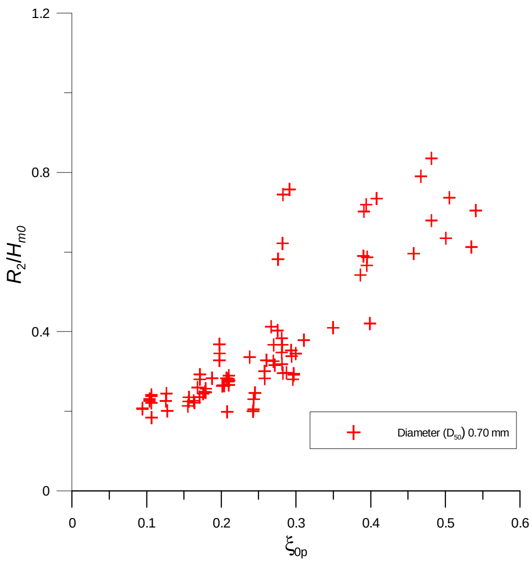

Figure 5.- R_2 results with Iribarren number for D_{50} 0.70 mm in the 3 modeled beaches (1/20; 1/30 y 1/50).

ANALYSIS AND DISCUSSION

For the analysis of the results hereinafter it is assumed that there are no significant differences between grain sizes. The data from the coarse grain size was used since its higher rugosity minimized the scale effects due to surface tension.

Comparison with chosen formulations

A homogenization of the different chosen formulations above was carried out in order to compare them, Table 3. For the equations the Iribarren number is calculated with the foreshore slope *m*, peak period T_p and deep waters significant spectral wave height H_{m0}. Although Ruggiero et al. (2001) has not been chosen in the comparison with a real storm (Figure 1) here is included in order to compare with more than one R_2-$H_{m0}L_0$, Eq.(2) .

Table 3.- Chosen Formulations. Parameter Homogenization

Author/rs	Equation
Hunt (1959)	$\frac{R_2}{H_{m0}} = \xi_{op}$
Holman (1986)	$\frac{R_2}{H_{m0}} = 0.83\xi_{op} + 0.20$
Mase (1989)	$\frac{R_2}{H_{m0}} = 1.86\xi_{op}^{0.71}$
Nielsen and Hanslow (1991)	$R_2 = 0.089 \cdot (H_{m0}L_0)^{0.5}$
Ahrens and Seeling (1996)	$\frac{R_2}{H_{m0}} = 3.15\xi_{op}$
Ruggiero et al. (2001)	$R_2 = 0.27m \cdot (H_{m0}L_0)^{0.5}$
Hedges and Mase (2004)	$\frac{R_2}{H_{m0}} = 1.49\xi_{op} + 0.34$

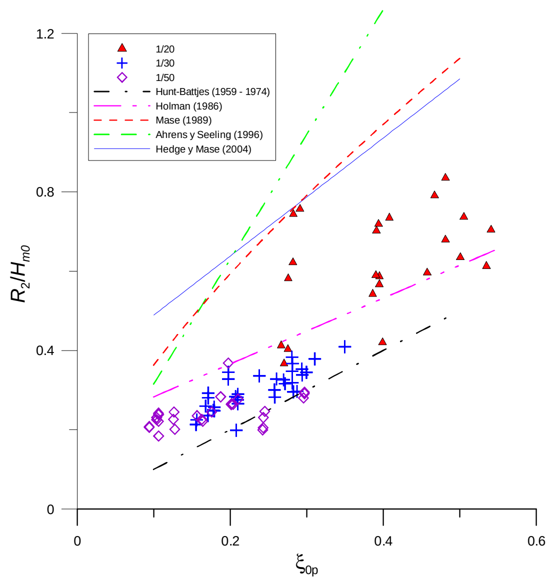

Figure 6.- R_2-ξ_{0p} with chosen formulation. Grouped by slopes.

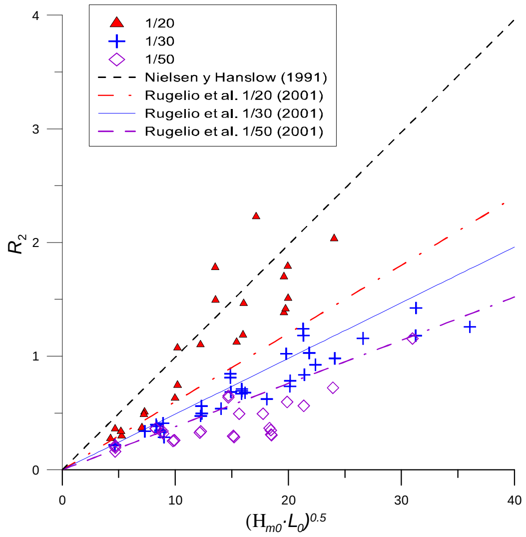

Figure 7.- R_2-$H_{m0}L_0$ with chosen formulation. Grouped by slopes. Units in meters.

For the R_2-ξ_{0p} formulations there are a maximum and minimum limits defined by Ahrens and Seeling (1996) and Hunt (1959) respectively, Figure 6. The equation of Holman (1986) provides best fit to the data what evidences the data goodness of the physical model due to this formulation comes from field experiment. Focusing on slope groups there is a remarkable change between dissipative and intermediate beaches (1/50 and 1/30) and reflective one (1/20). For the non-reflective model beaches the formulation yield by Holman (1986) should be appropriate, but understimates the runup for reflective beaches, in this case the runup prediction would be more appropriate with Mase et al. (2004).

The other kind of formulations considered in this study, R_2-$H_{m0}L_0$, are also compared with the data experiments, Figure 7. There is a maximum limit traced by Nielsen and Hanslow (1991) that overestimates the R_2 in almost the most of the cases. This formulation presents the problem of not including the beach slope in the formulation. The data evidence the grouping of the results by slopes, what indicates the relevancy of this parameter in the R_2 estimation what is also addressed in other studies (Mase, 1989). The other formulation considered, Ruggiero et al. (2001), is a good estimation for intermediate cases, but underestimates reflective beach and overestimates dissipative one.

It was observed an increase in the dispersion of data for 1/20 slope and hence for higher Iribarren numbers, the reason of this problem is not clear but higher reflections in the flume could be one of them. Similar dispersion is observed in others similar experiments (Mase and Iwagaki, 1984; Stockdon et al., 2006).

Runup Parametrization

The analysed formulations predict R_2 with enough accuracy for specific cases dependending on the beach (reflective-dissipative) but they are not able to calculate adequately the parameter in all the considered cases. For this reason an analysis of the results with the aim of better estimation of runup in the data set was carried out.

The R_2-$H_{m0}L_0$ estimation groups the data by slope thus allowing to perform a statistic regression of the results depending on the beach slope. so that in Eq.(2) constant K_2 is a function of m. Once is calculated K_2 for each beach slope, an adjustment of them in function of slope was done. The best fit is potential, due to the progressive increment of K_2 in function of m, hence the equation for estimation of K_2 can be expressed as follow Eq.(3). This Eq.(3) can be introduced in R_2-$H_{m0}L_0$ and R_2-ξ_{0p} formulations what conduced to Eqs.(4) and (5)

$$K_2 = 4 \cdot \mathrm{m}^{1.3} \quad (3)$$

$$R_2 = 4 \cdot \mathrm{m}^{1.3} \cdot (H_{m0} L_0)^{0.5} \quad (4)$$

$$\frac{R_2}{H_{m0}} = 4 \cdot \mathrm{m}^{0.3} \cdot \xi_{op} \qquad (5)$$

Proposed formulation enhances the prediction in the data set (Figure 8). The high weight of the slope introduced in the equation R_2-ξ_{0p} (5) allows a better performance. The results are more accurate, in contrast with the cases without the slope correction (Figure 6) where the tendency of the intermediate and dissipative beaches (1/30 and 1/50) are clearly different in respect to the reflective one (1/20).

It is also remarkable that Eq.(5) do not introduce a constant in the equation, the physic of a constant in a R_2 formulation make sense when is split the contribution of setup, then the constant can be related with the setup (Mase et al., 2004). Since the Eq.(5) includes setup in estimation of R_2 constant should be nule, independently of a better statistic correlation. The setup contribution is hard to predict due to several process involved such as breaking or long waves.

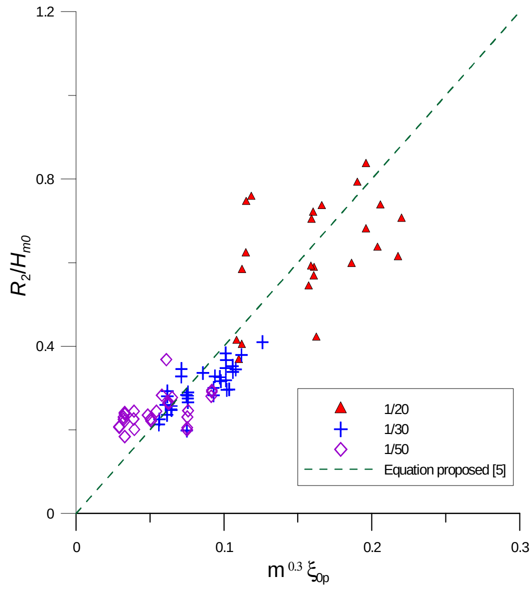

Figure 8.- Correction proposal for R_2 estimation. Data grouped by slopes

CONCLUSIONS

Physical model experiments with mobile bed were carried out for the estimation of R_2 in three different modelled beaches with slopes 1/50, 1/30 and 1/20 with two grain sizes. The Iribarren number varied between 0.1 and 0.6. Formulations available for runup assessment were chosen and compared with the results of experiments, through a parameter homogenization, so that the Iribarren number ξ_{0p} were calculated with the peak period T_p and deep waters significant spectral wave height H_{m0}, and with the foreshore slope *m*. The runup referred to the R_2 calculated with the peak method.

Within the chosen formulations, R_2-$H_{m0}L_0$ and R_2-ξ_{0p}, there was some clear limits: Hunt (1959) is a minimum and Ahrens and Seeling (1996); Ruggiero et al. (2001) and Mase et al. (2004) are maximum limits. The formulations studied predict some of the cases with good accuracy but are not be able to predict with enough accuracy the whole of the data, for example Holman (1986) has a good performance with dissipative and intermediate cases (1/50 and 1/30) but underestimated the values for the reflective beach (1/20).

The data were analyzed with the aim of seeking a relation that improve the estimation of R_2 in the data set reducing scatter. A relation that gave more weight to the slope in the R_2-ξ_{0p} has been proposed, enhancing the accuracy of the prediction. It is seems that in the R_2-ξ_{0p} formulation the foreshore slope, m , has not got enough weight for the R_2 assessment due to the rationed with the square of wave steepness.

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