INFLUENCE OF FALSE WAVES
ON WAVE RECORDS STATISTICS

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ABSTRACT

Wave discretization is a usual procedure in ocean engineering for the statistical analysis of wave records. Different criteria can be used for performing that discretization. The orbital criterion presents important advantages with respect to the zero-up-crossing criterion, more commonly used. These criteria provide significantly different statistical results, as shown when applied to wave records from the scalar Waverider buoy of Valencia, off the Mediterranean Spanish coast.

INTRODUCTION

Statistical parameters, as the significant wave height and the mean wave period, are commonly used in coastal and maritime engineering applications. However, wave statistics depend on the criterion used for discretizing waves in a wave record. The zero-up-crossing (ZUC) criterion is the most widely used up to now. Recently, Giménez *et al.* (1994a) have proposed a new criterion for discretizing waves that is based in the analysis of the combined vertical and horizontal movement of a particle in the sea surface, and not only of its vertical movement as done by the other available criteria. The so-called *orbital criterion* has been shown to be more consistent and robust, and to have less variability than the ZUC criterion.

This paper presents the different results obtained when applying the ZUC and orbital criteria for the statistical analysis of wave records from a waverider buoy installed in front of the Valencia harbour in the Spanish coast. The accomplished comparison of both criteria in the time domain clearly shows the superiority of the

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orbital criterion for the statistical analysis of wave records, giving results in better accordance with theoretical values.

ORBITAL CRITERION AND FALSE WAVES

In the ZUC criterion, a discrete wave is defined by two consecutive up-crossings of the mean level, that is, a complete cycle of vertical movement. As a consequence, results are very sensitive to the presence of small ripples in the sea surface as well as to the unavoidable noise in the measuring and transmission systems. In the orbital criterion, a discrete wave corresponds to a complete rotation of a surface point around its mean position. This rotation involves a complete cycle of both vertical and horizontal movement. For this reason, there could be ZUC waves that are not orbital waves: they are called false waves, since they lack some important properties that one would like to be fulfilled by progressive waves.

Fig. 1(a) shows a piece of a real wave record with three zero-up-crossings, denoted as A, B, C, and therefore two waves AB and BC according to the ZUC criterion. Fig. 1(b) shows the corresponding orbital representation in the complex plane, making it clear that there is only one complete rotation from A to C. Therefore, there is only one wave according to the orbital criterion, as indicated in Fig. 1(c). The aforementioned can also be applied to the piece of wave record shown in Fig. 2.

ADVANTAGES OF THE ORBITAL CRITERION

The presence of noise in a wave record results in the appearance of small waves that do not actually exist. Giménez *et al.* (1994a) have shown that most of them are false waves. Since the orbital criterion eliminates false waves, it is less sensitive to noise than the ZUC criterion. For instance, a 5% of noise results in an underestimation of the actual mean wave period of about a 5% -same level as noise- when using the orbital criterion. On the contrary, the error tends to be as high as a 20-25% when using the ZUC criterion. Furthermore, the orbital criterion is physically more consistent and, as proved by Giménez *et al.* (1994b), the mean period of orbital waves presents less sampling variability than the mean period of ZUC waves. Using ARMA random wave numerical simulations, Sánchez-Carratalá (1995) has pointed out the very good fitting of the sampling variability of many sea state parameters achieved when the orbital criterion for discretizing waves is used.

Advantages of the orbital criterion can be extended to the analysis of directional seas. As proposed by the IAHR Working Group on Wave Generation and Analysis (1989), the mean wave direction is commonly used as the representative direction of a directional sea state. The mean direction was defined by Longuet-Higgins (1957), and corresponds to the direction in which the energy is propagated. Therefore, its determination is essential in the study of many engineering problems, such as evaluation of longshore sediment transport or pollutant propagation and dispersion. Giménez and Sánchez-Carratalá (1997) have shown that the mean direction is the direction that presents the maximum number of orbital waves. Therefore, energy propagation is associated with orbital waves rather than with ZUC waves.

INFLUENCE OF THE DISCRETIZATION CRITERION ON WAVE STATISTICS

As mentioned above, Figs. 1 and 2 show two examples of the presence of false waves in real wave records. However, there is a significant difference between both of them. On the one hand, the false wave in Fig. 1 has its crest before its trough, and henceforth will be named crest-trough or CT-type false wave. On the other hand, the false wave in Fig. 2 has its trough before its crest, and consequently will be named trough-crest or TC-type false wave. It can be noted that the presence of false waves of any type results in one orbital wave whose wave period is the sum of the two corresponding ZUC wave periods. Therefore, the mean orbital wave period $\overline{T}_r$ will always be greater or equal than the mean ZUC wave period $\overline{T}_z$.

As shown by Longuet-Higgins (1958), following Rice (1954), the mean ZUC wave period for Gaussian waves is T_{02}. On the other hand, Giménez *et al.* (1994a) have proved, both mathematically and numerically, that the mean orbital wave period is T_{01}. The value of these spectral parameters is given by the following expression:

$$T_{ij} = \sqrt[j-i]{\frac{m_i}{m_j}} \tag{1}$$

where m_n is the *n*th order moment of the variance spectrum $S_\eta(f)$:

$$m_n = \int_0^\infty f^n S_\eta(f)\,df \tag{2}$$

and f is the frequency. It can be mathematically proved that $T_{01} \geq T_{02}$, in accordance with the fact that $\overline{T}_r \geq \overline{T}_z$.

The way in which a false wave affects the wave heights of a wave record depends on its type. On the one hand, a CT-type false wave, as the one shown in Fig. 1, results in a small ZUC wave followed by a higher one; the height of the corresponding orbital wave is the same as the higher ZUC wave. On the other hand, a TC-type false wave, as the one shown in Fig. 2, results in two medium-sized ZUC waves; the height of the corresponding orbital wave is higher than both ZUC waves. As a consequence, the value of any statistical wave height parameter (mean wave height, root mean square wave height, significant wave height) is greater for orbital waves than for ZUC waves. Furthermore, the distribution of orbital wave heights presents less small waves (because of CT-type false waves), less medium-sized waves (because of TC-type false waves) and more high waves (because of TC-type false waves).

The elimination of small ripples observed in real wave records is a usual procedure in ocean engineering. For instance, Rye (1974) and Thompson and Seelig (1984) propose to remove the waves whose height or period do not reach certain threshold values, because these waves are considered of secondary interest for

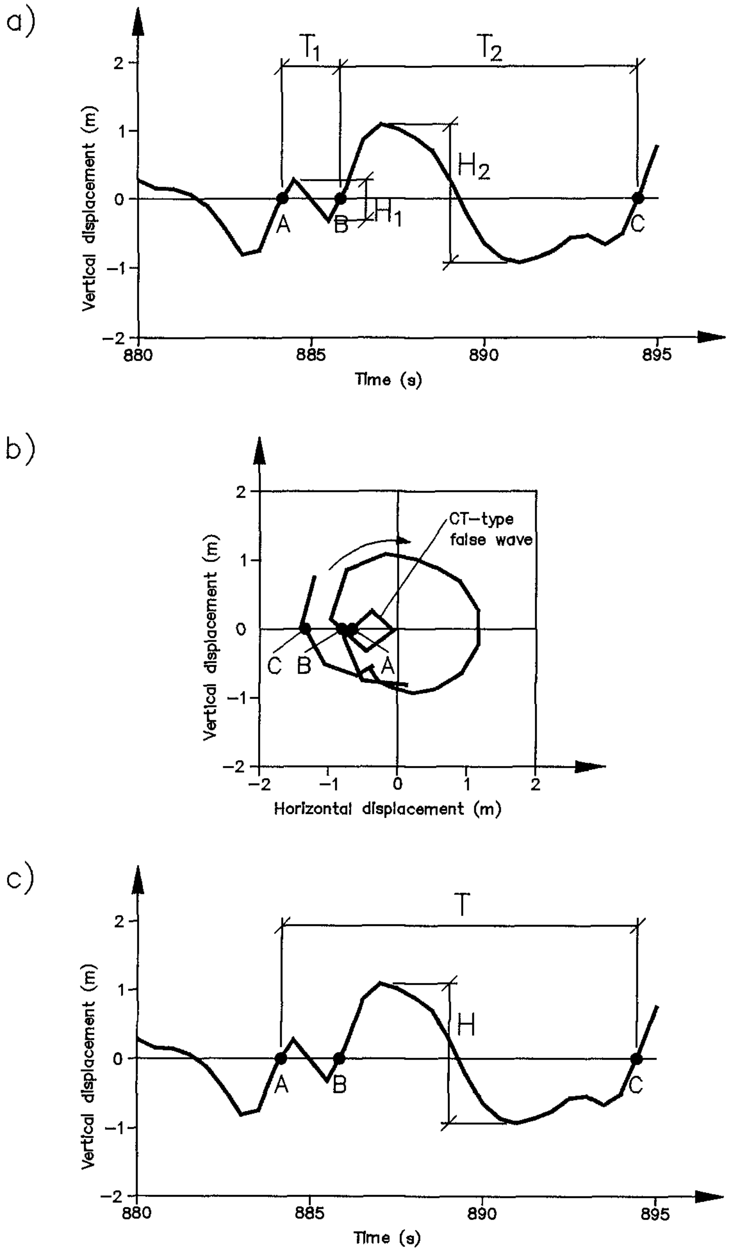

Figure 1. Example of CT-type false wave in wave record 0900010395V: a) ZUC waves; b) orbital analysis; c) orbital wave.

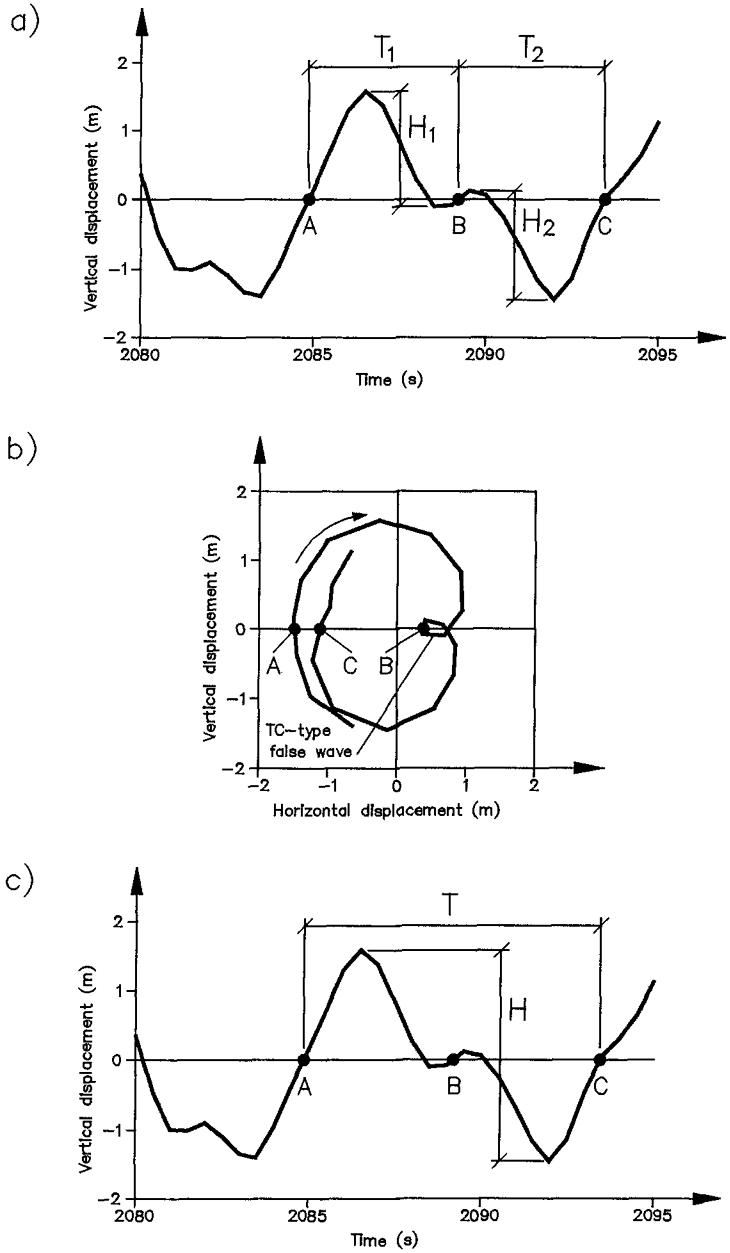

Figure 2. Example of TC-type false wave in wave record 0100010395V: a) ZUC waves; b) orbital analysis; c) orbital wave.

RECORD No.	1	2	3	4
Denomination	0100010395V	0500010395V	0900010395V	1300010395V
Date	3-1-95	3-1-95	3-1-95	3-1-95
Hour	1:00	5:00	9:00	13:00

Table 1. Description of the analyzed wave records.

engineering applications. These threshold values are obviously arbitrary, and they generally only remove the ripples that are ZUC waves, that is, the CT-type false waves. In this sense, the orbital criterion is more consistent and not arbitrary, and can be effectively used to avoid the effect of noise in wave records as suggested by Kitano and Mase (1998).

Using numerical simulations, Giménez *et al.* (1994b) have proved that wave statistics are altered by the selection of the wave discretization criterion. Pires-Silva and Medina (1994) have obtained significant differences in the mean periods of wave records from a waverider buoy located off the west coast of Portugal. In the next section, the results of applying the orbital and ZUC criteria to wave records from the scalar buoy of Valencia are analyzed.

WAVE RECORDS STATISTICS

The scalar buoy of Valencia is a Waverider buoy located in front of the Valencia harbour, off the Mediterranean Spanish coast, at 20 m water depth. Table 1

RECORD No.	1	2	3	4
m_0 (m^2)	0.579	0.469	0.486	0.404
T_{01} (s)	6.73	6.78	7.18	6.44
T_{02} (s)	6.14	6.10	6.51	5.85
$(8m_0)^{1/2}$ (m)	2.15	1.94	1.97	1.80
H_{m0} (m)	3.04	2.74	2.79	2.54
π_f (%)	8.9	10.0	9.2	9.3
Q_e	2.23	2.68	3.86	2.57
γ_{Q_e}	0.80	1.63	3.75	1.44

Table 2. Spectral parameters of the analyzed wave records.

indicates the analyzed wave records, that have been taken from a storm with a return period of about 2 years, happened on March 1, 1995. Record length is 5120 points, and sampling interval 0.5 s. Fig. 3 shows the smoothed variance spectra of the analyzed records, with 32 degrees of freedom in each spectral component.

Spectral parameters

Table 2 shows some spectral parameters of the wave records. The parameters m_0, T_{01} and T_{02} have been defined in Eqs. (1) and (2), while $(8m_0)^{1/2}$ and $H_{m0}=4m_0^{1/2}$ are, respectively, the spectral estimations of the root mean square wave height and the significant wave height. The parameter $\pi_f=1-T_{02}/T_{01}$, that appears in Table 2 as a percentage, is the spectral estimation of the rate of false waves (see Giménez *et al.*, 1994a). Q_e is the spectral peakedness parameter introduced by Medina and Hudspeth (1987), divided by two for correcting its sampling bias, as indicated by van Vledder (1992) following Elgar *et al.* (1984). Finally, γ_{Q_e} is the peak enhancement factor of the JONSWAP-Goda spectrum (see Goda, 1979) that has the same value of Q_e.

Statistical parameters

Table 3 shows the number of orbital waves, N_r, and ZUC waves, N_z, that result of applying both criteria to the analyzed wave records. The parameter $p_f=1-N_r/N_z$, expressed in Table 3 as a percentage, is the rate of ZUC waves that are false waves. As it can be observed, its value is about a 10% for the storm under consideration.

Table 4 presents a set of wave height and period statistical parameters. The parameters $\bar{T}$, H_{rms} and $H_{1/3}$ are, respectively, the mean wave period, root mean square wave height and significant wave height. The subscripts *r* or *z* are used to indicate whether the orbital or the ZUC criterion has been applied. The relations between the values corresponding to both criteria are also given. As predicted by the theory, the mean orbital wave period is greater than the corresponding ZUC value, about a 10% for the analyzed wave records. The same can be stated for the characteristic orbital wave heights, that are greater, about a 5-7% in the case of H_{rms} and a 2-4% in the case of $H_{1/3}$, than the corresponding characteristic ZUC wave heights.

Figs. 4 and 5 show, respectively, the distributions of normalized wave heights and wave periods of the analyzed wave records. According to the theory, the use of

RECORD No.	**1**	**2**	**3**	**4**
N_r	376	368	351	383
N_z	411	408	390	431
p_f (%)	8.5	9.8	10.0	11.1

Table 3. Number of waves and percentage of false waves in the analyzed wave records.

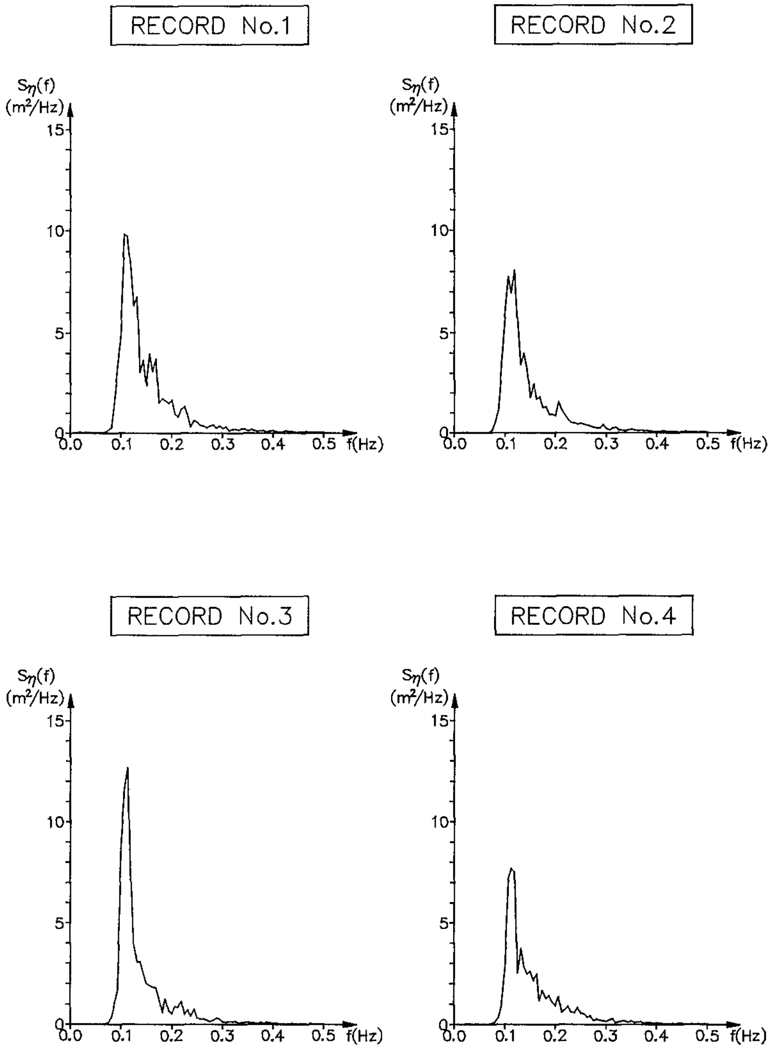

Figure 3. Smoothed variance spectra of the analyzed wave records.

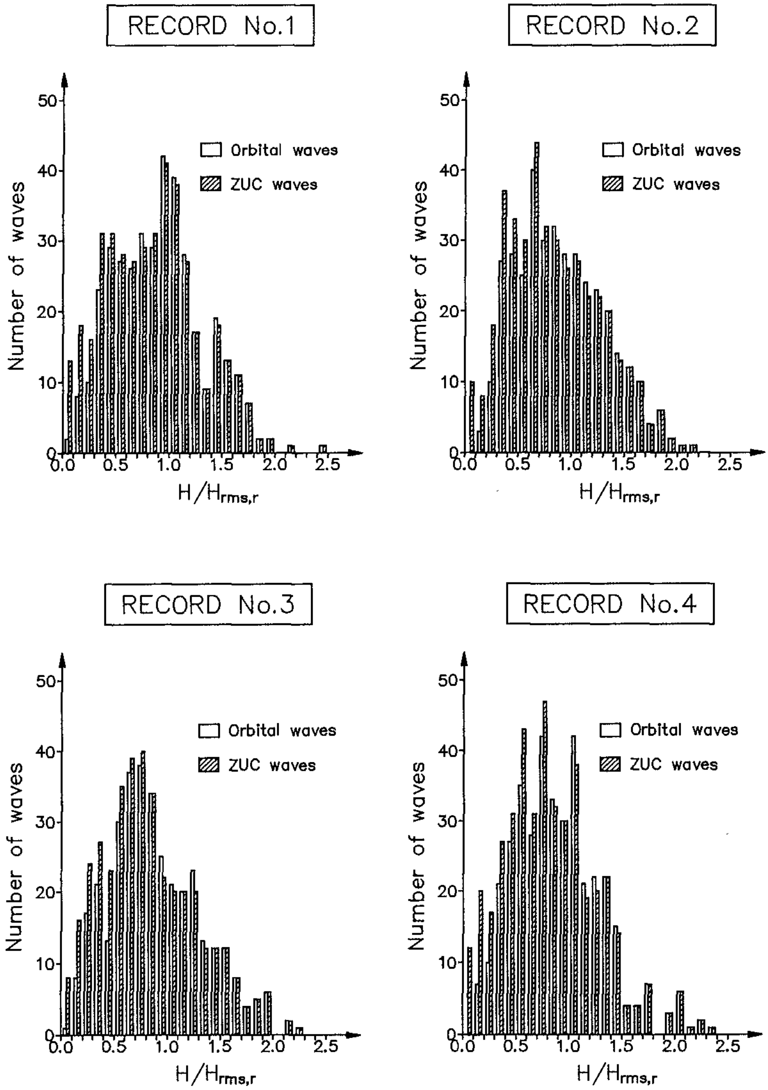

Figure 4. Distributions of normalized wave heights of the analyzed wave records.

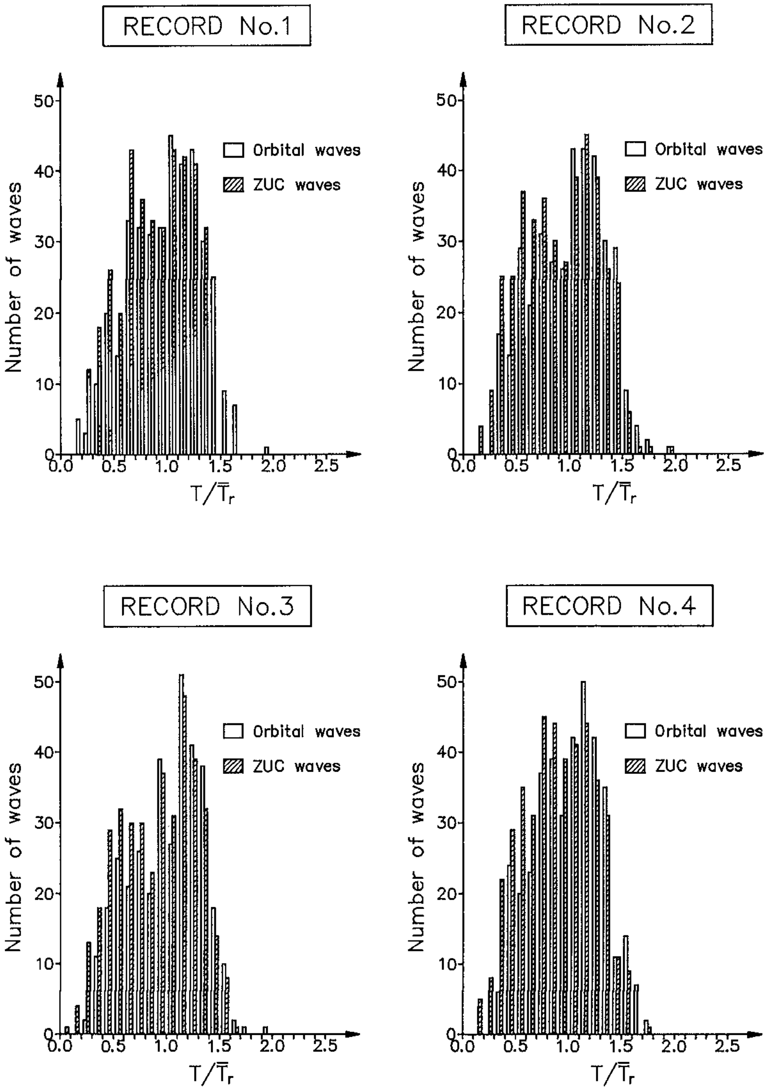

Figure 5. Distributions of normalized wave periods of the analyzed wave records.

RECORD No.	1	2	3	4
$\bar{T}_r$ (s)	6 78	6 93	7 25	6 65
$\bar{T}_z$ (s)	6 20	6 25	6 53	5 91
$\bar{T}_r / \bar{T}_z$	1 093	1 109	1 111	1 125
$H_{rms,r}$ (m)	2 15	1 93	1 98	1 81
$H_{rms,z}$ (m)	2 05	1 83	1 87	1 70
$H_{rms,r} / H_{rms,z}$	1 049	1 059	1 059	1 067
$H_{1/3,r}$ (m)	2 96	2 69	2 79	2 49
$H_{1/3,z}$ (m)	2 89	2 61	2 69	2 40
$H_{1/3,r} / H_{1/3,z}$	1 024	1 029	1 036	1 037

Table 4. Statistical parameters of the analyzed wave records

the orbital criterion results in less small and medium-sized waves, and more high waves Furthermore, the number of short period waves decreases, while the number of large period waves increases

Table 5 indicates, both for the orbital and the ZUC criteria, the values of the covariance coefficient between successive wave heights

$$c_{HH}(1) = \frac{\frac{1}{N-1}\sum_{i=1}^{N-1}\left(H_i - \bar{H}\right)\left(H_{i+1} - \bar{H}\right)}{\sigma_H^2} \tag{3}$$

RECORD No.	1	2	3	4
$c_{HH,r}$ (1)	0 337	0 351	0 426	0 226
$c_{HH,z}$ (1)	0 298	0 332	0 366	0 199
$c_{HH,r}$ (1) / $c_{HH,z}$ (1)	1 131	1 057	1 164	1 133
$c_{HT,r}$ (0)	0 612	0 609	0 608	0 551
$c_{HT,z}$ (0)	0 720	0 723	0 701	0 690
$c_{HT,r}$ (0) / $c_{HT,z}$ (0)	0 850	0 843	0 866	0 799

Table 5. Covariance coefficients of the analyzed wave records

where $\overline{H}$ and σ_H are, respectively, the mean and standard deviation of wave heights Table 5 also includes the values of the covariance coefficient between wave height and wave period

$$c_{HT}(0)=\frac{\frac{1}{N}\sum_{i=1}^{N}\left(H_i-\overline{H}\right)\left(T_i-\overline{T}\right)}{\sigma_H\,\sigma_T} \qquad (4)$$

where $\overline{T}$ and σ_T are, respectively, the mean and standard deviation of wave periods

As shown in Table 5, $c_{HH}(1)$ for orbital waves is up to a 16% greater than the corresponding value for ZUC waves This difference is a consequence of the elimination of small ripples in the sea surface that can significantly distort the length of run of wave groups (see Giménez *et al* , 1999) On the contrary, $c_{HT}(0)$ has a smaller value, about a 15-20%, when applying the orbital criterion In fact, most of the false waves that can be found in a wave record have both small height and small period, and therefore they contribute to a greater value of $c_{HT}(0)$ when the ZUC criterion -that does not eliminate those false waves- is used

Relations between statistical and spectral parameters

Table 6 presents the relations between statistical parameters and their corresponding spectral estimations observed in the analyzed wave records The following results can be remarked both the mean orbital wave period $\overline{T}_r$ and mean ZUC wave period $\overline{T}_z$ are close to their respective theoretical values, T_{01} and T_{02}, the root mean square orbital wave height is almost equal to its spectral estimation, while the corresponding results with ZUC waves differ about a 5%, the significant orbital wave height differs about a 2% with respect to its spectral estimation, while this

RECORD No.	**1**	**2**	**3**	**4**
$\overline{T}_r / T_{01}$	1 006	1 023	1 011	1 032
$\overline{T}_z / T_{02}$	1 010	1 025	1 002	1 010
$H_{rms,r} / (8m_0)^{1/2}$	0 998	0 998	1 004	1 007
$H_{rms,z} / (8m_0)^{1/2}$	0 952	0 943	0 948	0 943
$H_{1/3,r} / H_{m0}$	0 972	0 982	0 999	0 980
$H_{1/3,z} / H_{m0}$	0 949	0 954	0 965	0 946
p_f / π_f	0 961	0 977	1 082	1 205

Table 6. Relations between statistical and spectral parameters of the analyzed wave records

difference increases to about a 5% in the case of ZUC waves; the false waves rate can oscillate over an interval of ±20% around its spectral estimation.

CONCLUSIONS

The results obtained with the application of the zero-up-crossing criterion for the analysis of real wave records are very sensitive to the presence of small ripples of secondary interest in ocean engineering, as well as to the unavoidable noise in the measuring and transmission systems. On the contrary, the orbital criterion is more consistent and robust, and avoids the arbitrary selection of threshold levels for removing small ripples in the statistical analysis.

The accomplished analysis of wave records from the scalar buoy of Valencia makes clear the influence of the selected discretization criterion on wave records statistics. The orbital wave heights and periods are, on the average, greater than the corresponding ZUC values, and show a better accordance with their corresponding spectral estimations.

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