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Experimental Study On The Wave Measurements Of Wave Buoys

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INTRODUCTION

Wave measurement is of vital importance for assessing the wave power resources and for developing wave energy devices, especially for the wave energy production and the survivability of the wave energy device. Wave buoys are one of the most popular measuring technologies developed and used for long-term wave measurements. In order to figure out whether the wave characteristics can be recorded by using the wave buoys accurately, an experimental study was carried out on the performance of three wave buoy models, viz two Wavescan buoys and one ODAS buoy, in a wave tank using the European FP7 MARINET facilities. This paper presents the test results in both time and frequency domains and the comparison between the wave buoys and wave gauge measurements. The analysis results reveal that for both regular and irregular waves, the Wavescan buoys have better performances than the ODAS buoy in terms of accuracy and the Wavescan buoys measurements have a very good correlation with those from the wave gauges.

Fig.1 The wave tank and buoy models

PHYSICAL MODEL

Tests were conducted in the wave tank in Ecole Central de Nantes, France. The wave tank is 50 m long, 30 m wide and 5 m depth, with a constant surface water temperature 10-20℃, see Fig.1. A segmented wave maker is located at one end of the tank composed of 48 paddles which are individually controlled by software, and could generate directional waves, including regular waves with maximum height of 1.1 m and irregular waves with maximum significant wave height of 0.6 m. At the other end of the wave tank, a parabolic rigid absorbing beach is located, at about 40 m away from the wave maker. The incident wave could be dissipated through the wave breaking processes during the wave tests.

The prototypes for this wave buoy model test are Wavescan and ODAS buoys, the models' dimensions are calculated referred to the prototypes. The test models include 1:8 and 1:16 scaled Wavescan models and a 1:11.25 ODAS buoy model, see Figure 1. The Wavescan buoy models are in disc shape, 55 mm and 27.5 mm thick separately, and the radii are 163 mm and 81.5 mm respectively for the 1:8 and 1:16 models. The ODAS buoy model is in cylinder shape with a cone at the bottom and 115 mm thick, and the radius of the cylinder is 89 mm.

Table 1 The statistical parameters for regular waves

Wave buoy type	1:16 Wavescan		1:8 Wavescan		ODAS buoy	
statistical parameter	H_m (m)	T_m (s)	H_m (m)	T_m (s)	H_m (m)	T_m (s)
Correlation Coefficients	0.9953	0.8847	0.9563	0.8406	0.9958	0.7534
Root Mean Square Error	0.0830	0.0710	0.1599	0.1650	0.0738	0.0676
Relative Error	3.84%	17.35%	7.22%	40.30%	3.41%	16.52%

DATA AQUISATION AND PROCESSING

The buoy models would be located in the wave tank with a lack mooring system, with 2 or 3 reflective markers placed on every buoy model, see Fig.2. The motions of the wave buoys in waves were measured using the Qualysis system, a non-intrusive measurement allowed to measure the motions of very small models (the model of 1:16 Wavescan weighs 220g). The time series of the motions of the buoy models could be recorded as the motions of the markers being captured with the frequency of 60Hz by high resolution cameras located around the wave tank.

The Qualysis system capture the optical signals of the target objects and transform the signals into the Cartesian Coordinates we need. As the lack mooring system was adopted during the tests, the buoy models had 6 degrees of freedom to move, while the heave motion was the most concerned one. For every marker, the Cartesian Coordinates could be able to be described with a rotation and translation matrix:

$$\begin{pmatrix} x \\ y \\ z \end{pmatrix} = R \begin{pmatrix} x_0 \\ y_0 \\ z_0 \end{pmatrix} + \begin{pmatrix} \xi_x \\ \xi_y \\ \xi_z \end{pmatrix}$$

which shows the relative movements between the marker and the gravity center of the buoy model. With the coordinates of the markers, the movements of the gravity centre of the buoy models can be deduced by computing the rotation matrix.

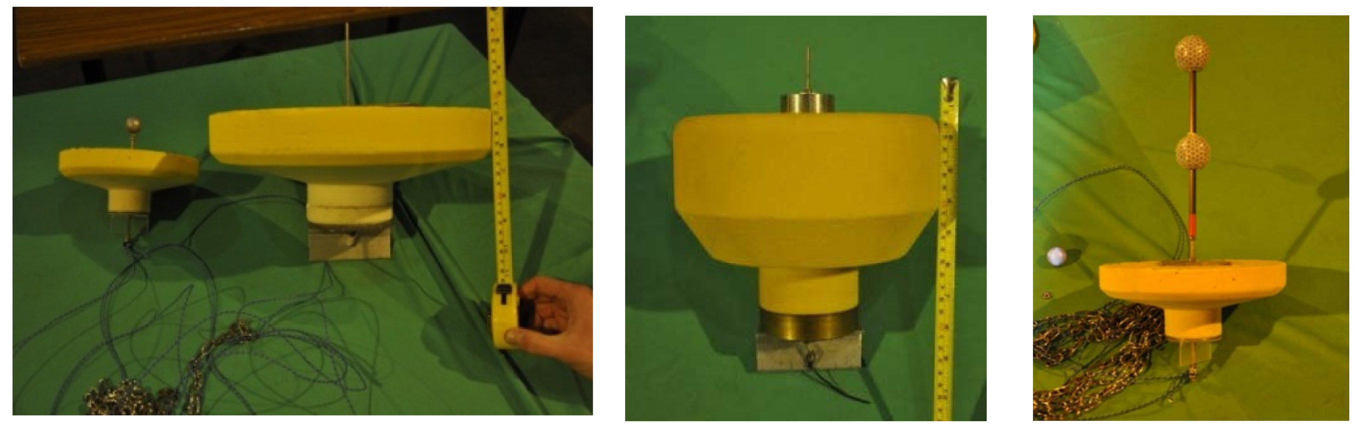

Fig.2 The wave buoy models and the reflective markers

TIME DOMAIN ANALYSIS

8 combinations of wave heights and periods were taken as the regular wave states during the wave tank tests. Time domain analysis are applied for the regular waves, and the cross-zero methods are used to calculate the wave characteristics, including the wave number, mean wave height, 1/3 wave height, 1/10 wave height, etc. For the typical regular waves, the mean wave height is equal to 1/3 wave height and 1/10 wave height so we take the mean wave height H_m and period T_m as our characteristic parameters. The time series of motions recorded by the wave gauges and buoy models are counted separately on the basis of zero-crossing criteria. the measurements by the 3 buoy models contrasted with those by the wave gauge are shown in Fig.3, where the axis R1-R4 are short for regular wave state numbers

Table 2 The statistical parameters for irregular waves

Wave buoy type	1:16 Wavescan		1:8 Wavescan		ODAS buoy	
statistical parameter	H_S (m)	T_P(s)	H_S(m)	T_P(s)	H_S (m)	T_P(s)
Correlation Coefficients	0.9984	0.9938	0.9963	0.9744	0.9894	0.9649
Root Mean Square Error	0.0225	0.0609	0.0296	0.1145	0.0360	0.1256
Relative Error	3.47%	1.87%	3.79%	3.05%	3.90%	2.27%

FREQUENCY DOMAIN ANALYSIS

For the irregular waves, both long crest and short crest, the generated waves are dominated by the spectral characteristics: significant wave height H_S and the peak period T_P. For the purpose of obtaining the spectral characteristics recorded by the wave gauge and buoy models, the Fast Fourier Transform (FFT) algorithm is applied on the calculations for the wave buoy models' data during irregular waves.

The wave energy density spectra *S(f)* are transformed from the time series of the movements of the buoy models with the aid of FFT algorithm, where *f* represents frequency. The significant wave height, the mean wave period and the spectral peak wave period can be calculated through the density spectra.

For the irregular wave states, the measured wave characteristics by the wave buoy models are shown in Fig.4 and all the buoy models results are compared with those of the wave gauge.

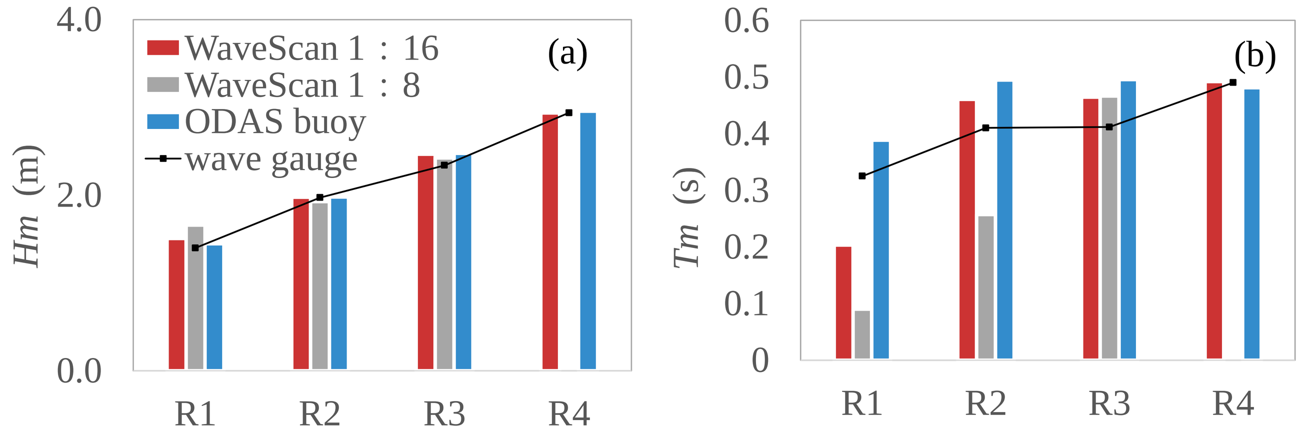

Fig.3 The measurement comparison during regular waves

COMPARISON AND DISCUSSION

The wave characteristics calculated by the buoy models are compared with those by the wave gauges and 3 statistical parameters are obtained, see Table 1-2. In General, all the buoy models show very good correlation with the wave gauges with CCs exceeding 0.95 during both regular and irregular wave states. The RMSEs during irregular waves seem less than those during regular waves: take the 1:16 Wavescan buoy model as an example, the RMSE for mean wave height is 0.0802m during regular wave states while the RMSE for significant wave height is 0.0225m during irregular wave states. On the other side, for wave periods measurements, the buoy models show much better performances during irregular wave states. All the REs for wave peak period are beneath 5% while for the regular wave states, the REs are quite large respectively, with a minimum of 16.72%.

Accordingly, for wave measurements, all the buoy models show good agreements with the wave gauges, especially during irregular wave states. The statistical parameters also reveal that, for both regular and irregular waves, the 1:16 Wave scan buoy model shows best correlation with the wave gauges and has the smallest measurement errors.

Besides, contrast tests were set in irregular wave states for Wavescan 1:16 buoy model to check if the mooring system would affect the movements of the buoys. The wave density spectral characteristics recorded by the buoy model with mooring systems located at different depth are drawn together with those from the wave gauges, see Fig.5.

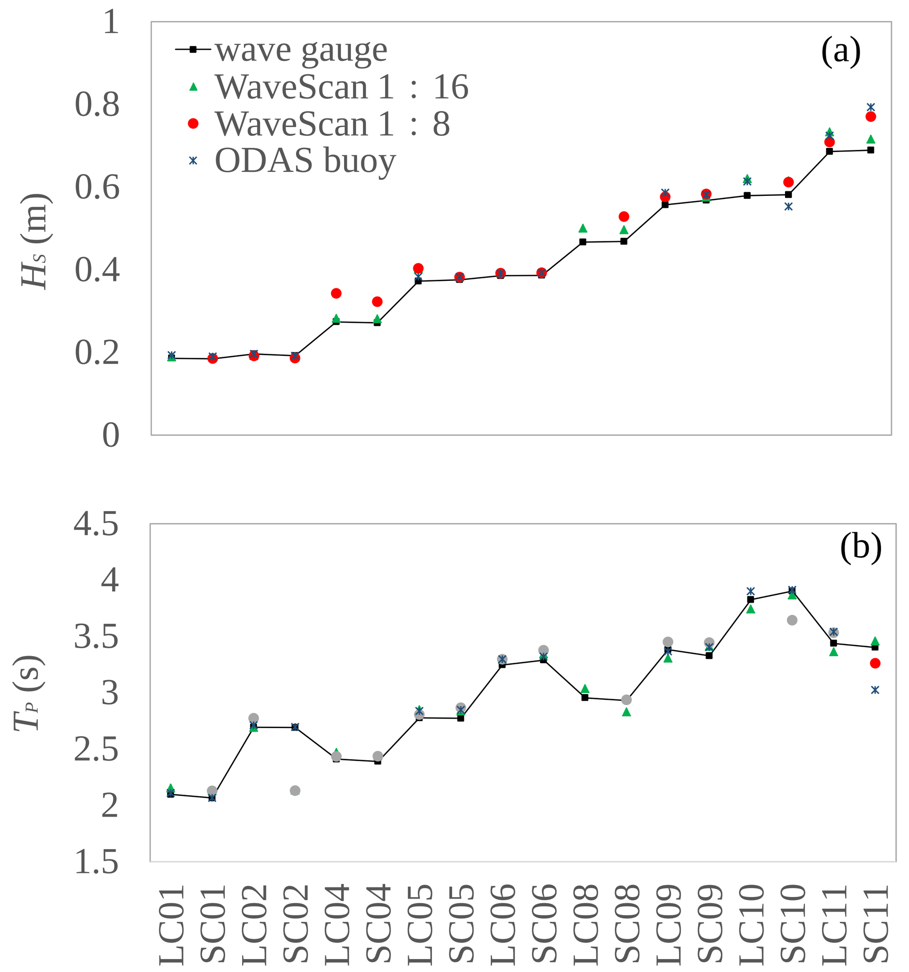

Fig.4 The measurement comparison during irregular waves

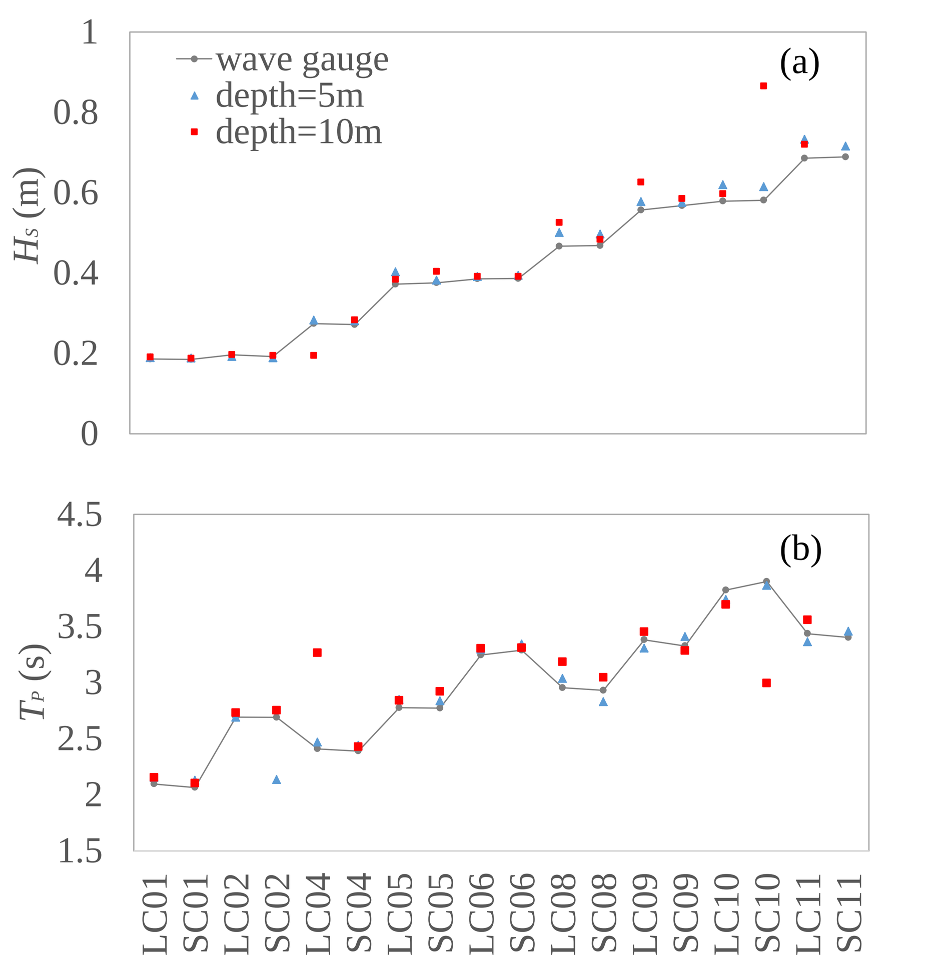

Fig.5 The measurement comparison between different mooring systems

CONCLUSIONS

Generally, the wave buoys give very good measurements to the waves for both regular and irregular waves, including the extreme waves and the short crested waves. For both regular and irregular waves, the correlation coefficients between the wave measurements by the wave buoys and the wave gauges are over 0.95, except for the wave periods results during regular wave cases. According to the statistical parameters, the buoys show better performances on measuring the irregular wave states as the relative errors are quite small for both significant wave heights and peak periods.

Among the 3 wave buoy models, the measurement performances by the 1:16 Wavescan buoy and the ODAS buoy are contrasted to find out the differences between the two kinds of buoys. For the regular waves, the ODAS buoy shows more close measurements to the wave gauge for wave height than the Wavescan buoy, especially when the wave period is very short. But for the other wave cases, the Wavescan buoy shows better performances. Moreover, the Wavescan buoy model has recorded 9 irregular wave cases out of 11, while the ODAS buoy made it 7. For the extreme irregular wave states, the two buoys have successfully recorded the wave characteristics and the results are accurate enough as wave measurements. Besides, the inter-comparison between the two Wavescan buoy models is conducted to investigate the effect of the size of the buoy. Compared with the 1:8 Wavescan buoy model, the 1:16 one performs better on measuring the wave surface, not only due to the fact that the smaller one provides a more complete measurement for both regular and irregular waves, but also because of the accuracy of the wave characteristics and even the wave energy density spectra. According to the contrast results for Wavescan buoys linked to mooring system located at different depth, the slack mooring system does not show overt effects on the wave measurements, except for the very extreme waves.

More physical tests and numerical simulations need to done to give a thorough analysis on the wave measurements using wave buoys. The effects of the dimensions of the buoys will be shown distinctive if more models can be investigated.

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