

# THE FOCUSING OF WATER WAVES BY ELLIPTICAL SUBMERGED LENSES



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## INTRODUCTION

The interactions between monochromatic water waves and submerged structures are examined in this study in order to find an effective way to focus wave energy in relatively small, delimited regions. The focusing of water waves by submerged structures, from here referred to as lenses, may be an efficient technique to increase potential wave energy for wave energy converters.

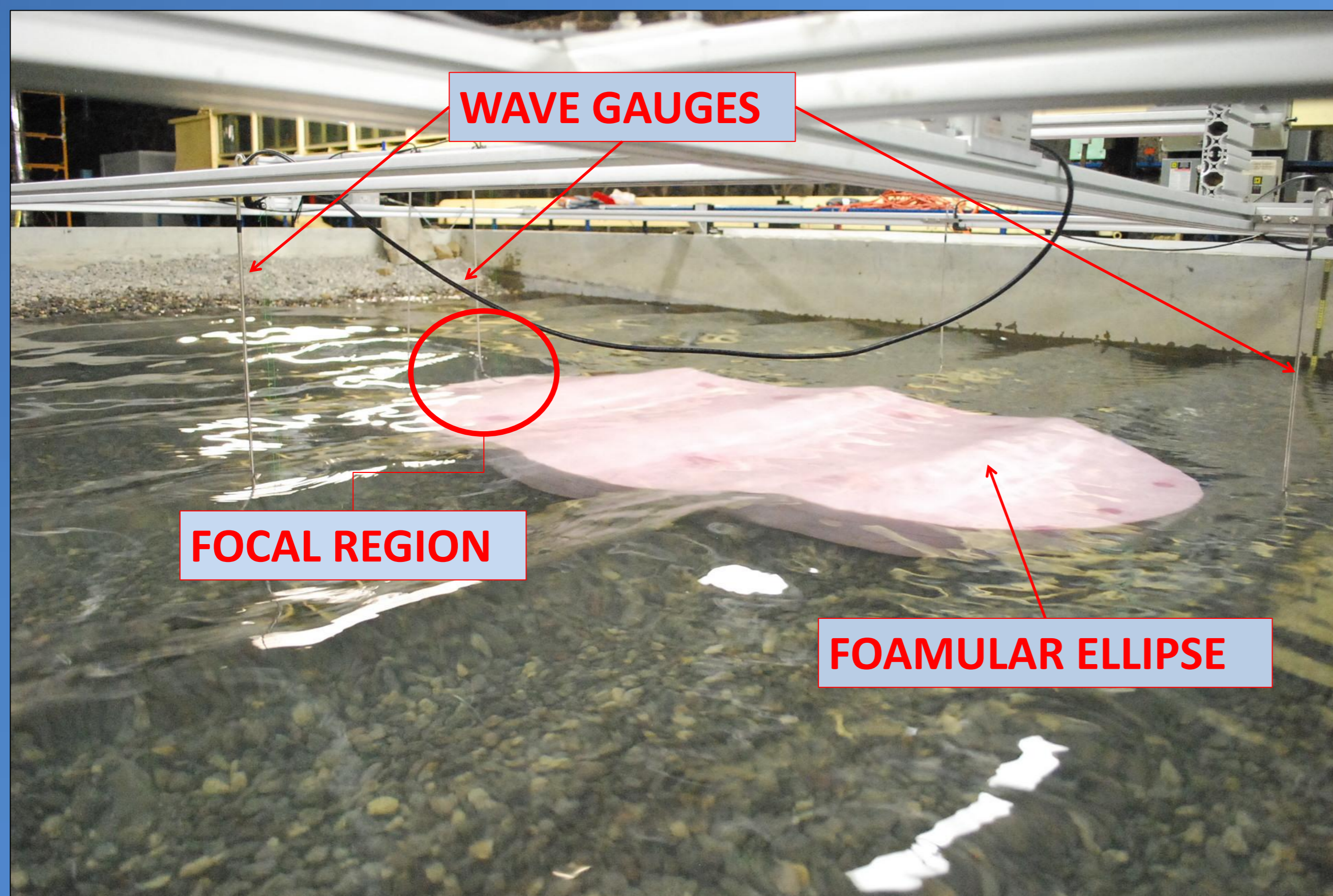


Figure 1.- Experimental set-up in the wave tank. The waves travel from right to left and the focal region appears near the far focus of the ellipse. The surface water elevation was measured with AWP-24 resistant-type sensors from AKAMINA Technologies.

## MOTIVATION

According to the ray tracing theory of geometrical optics, which is used here as an analogous process for focusing water waves, a wide beam of rays parallel to the optical axis will be refracted by the elliptical lens and converge at the far focus point of the ellipse. In the case of water waves, it is expected that the refraction process, caused by the change in depth of the elliptical mount, will behave in a similar way. However, there is some uncertainty about this assumption as the length of water waves is much longer than that of electromagnetic type. Given the above and in order to find the best way of maximizing the wave energy, the following question arises: what is the relation between the lens shape parameters and the amplification of water wave energy at the focal point?

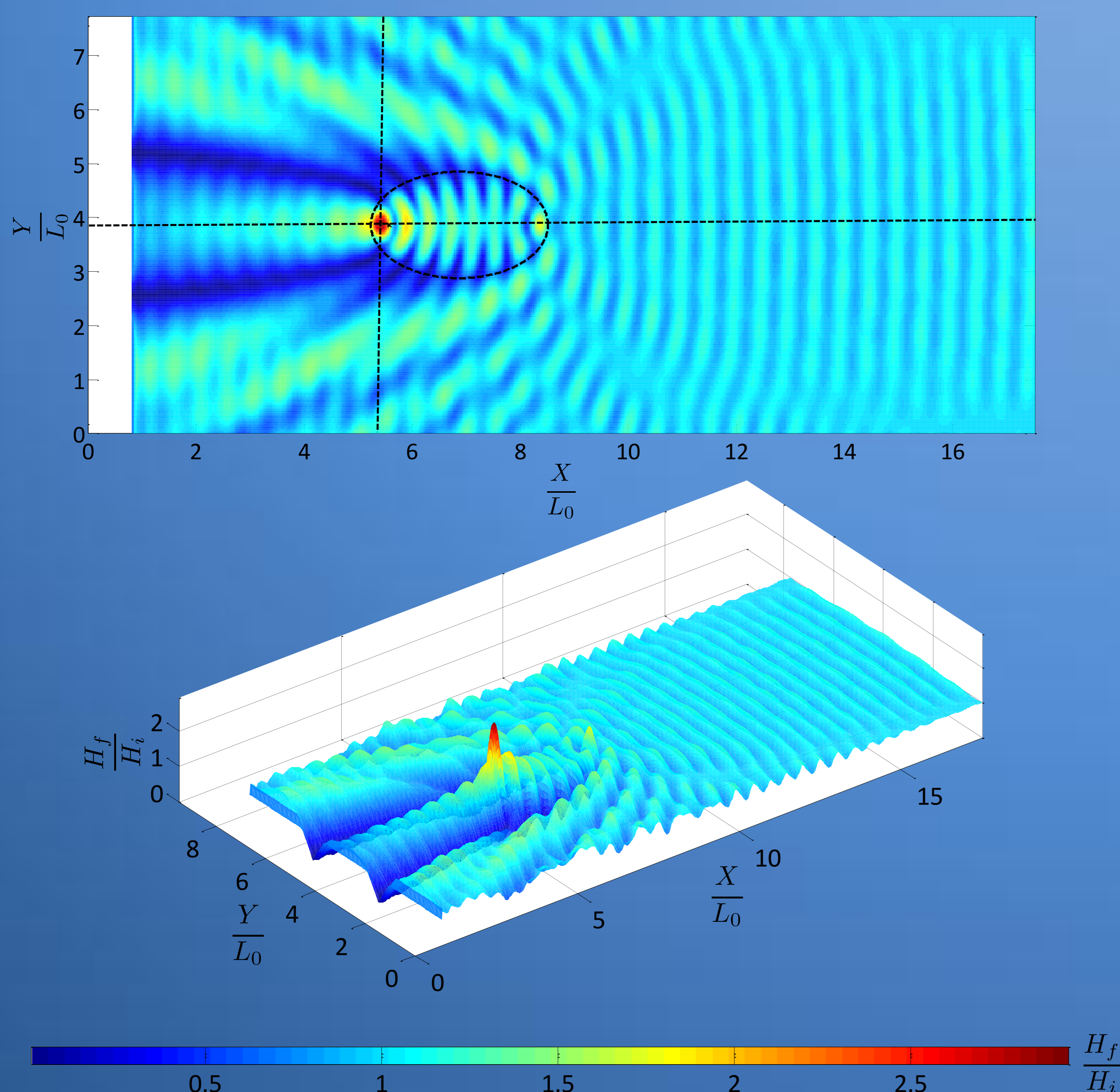


Figure 2.- Numerical results in 2D (top) and 3D (bottom). The color axis represents the ratio between the focalized ( $H_f$ ) and the incident ( $H_i$ ) wave height. The X and Y spaces are normalized by the incident wave length ( $L_0$ ).

To answer this, several numerical and physical tests were executed in order to find a relationship between the enhancement of the wave amplitude in function of the eccentricity and size of the semi-major and semi-minor axes.

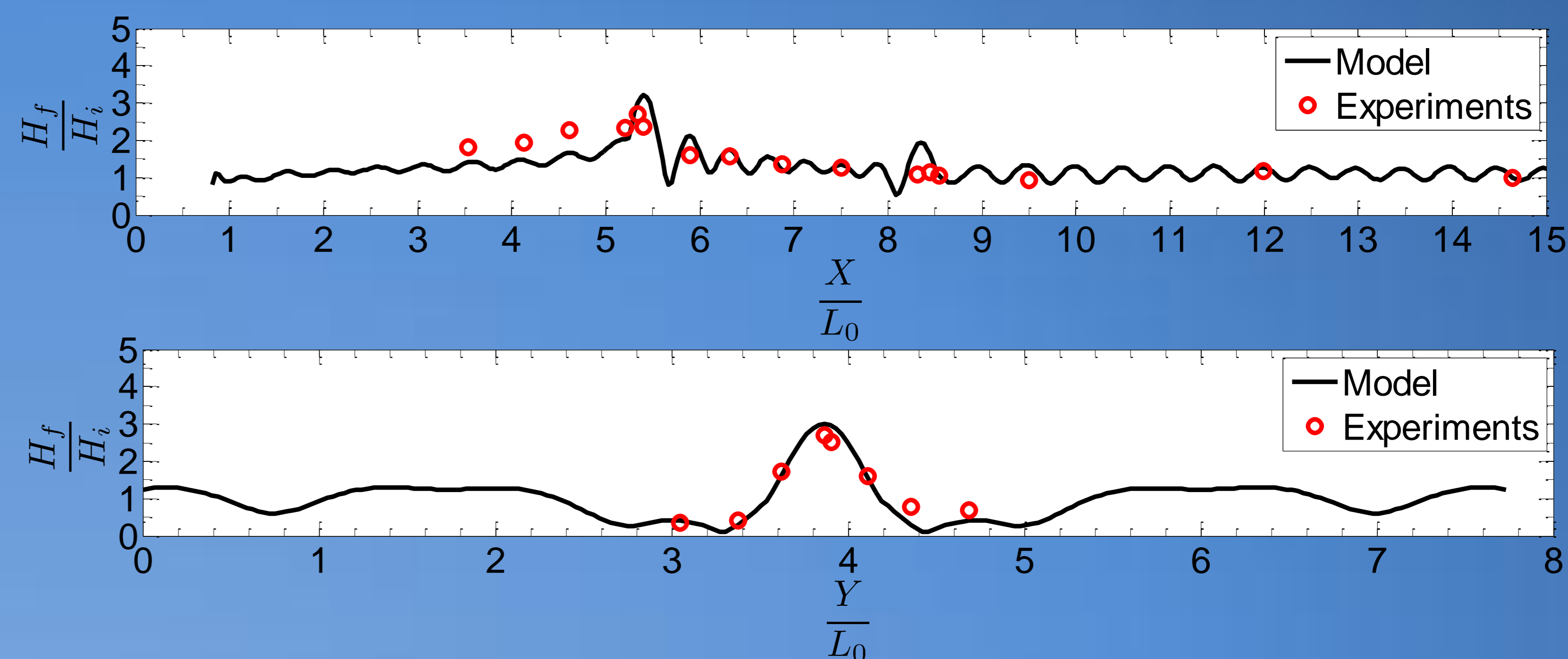


Figure 3.- Comparison of computed normalized wave height obtained by the model and the measurements acquired at the wave tank in the horizontal (top) and vertical (bottom) transects.

## EXPERIMENTS AND NUMERICAL IMPLEMENTATION

The experimental tests were carried out in a narrow wave tank with a flap type wave generator (Figure 1) at the National Autonomous University of Mexico. The 2-D numerical tests (Figure 2) were performed with the model WAPO2D (*WAVE Propagation On the coast in 2 Dimensions*) developed by Silva *et al.* (2005). This model approximates the velocity potential by means of the modified mild slope equation (Silva *et al.* 2002b), which includes the refraction and diffractive terms and also includes energy dissipation caused by bottom friction (Kirby and Dalrymple, 1994) as well as wave breaking (Dally *et al.* 1985).

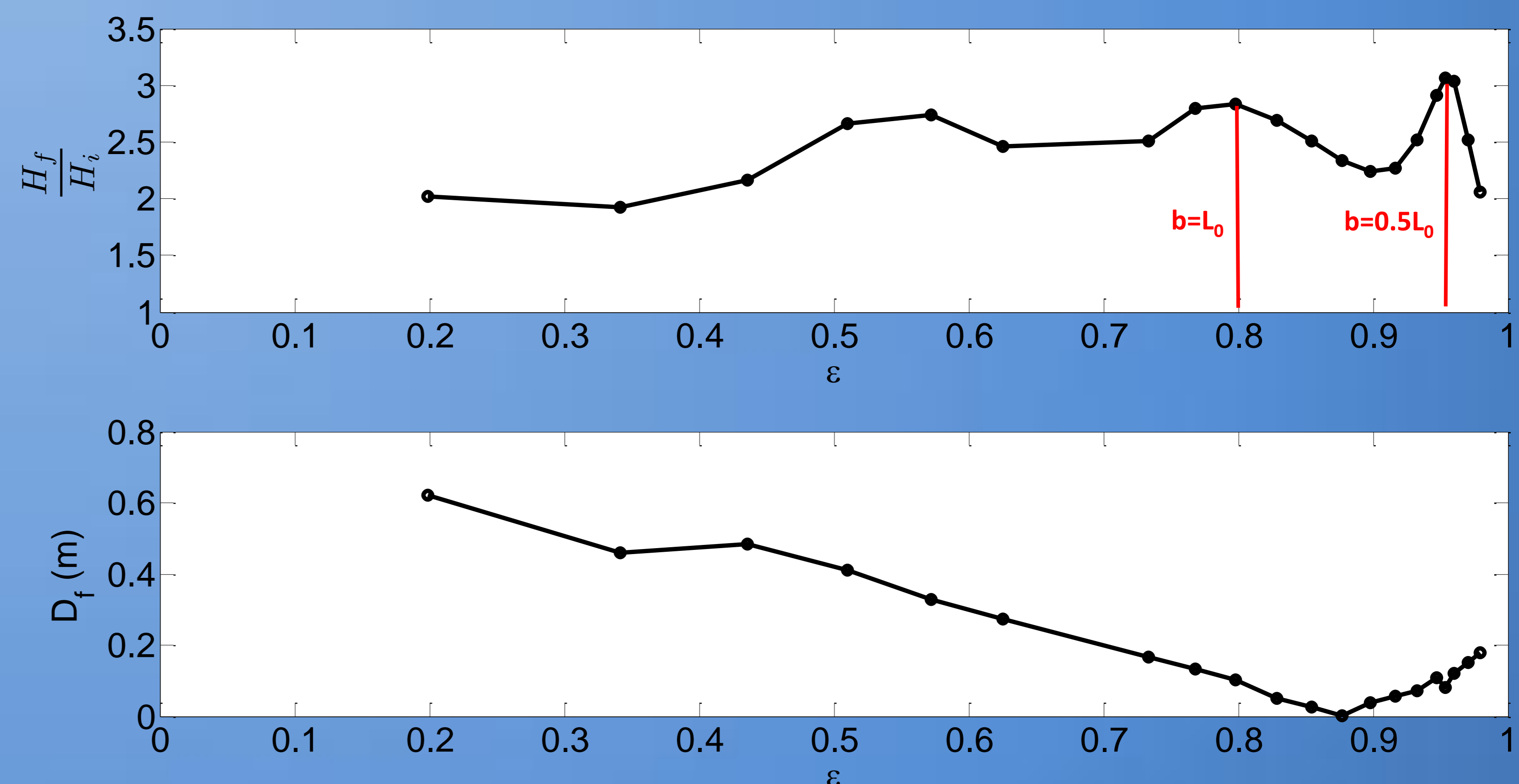


Figure 4.- Normalized wave height (top) and focal distance (bottom) in function of eccentricity. The maximum enhancement is achieved when the semi-minor axis is equal to one half of the incident length. The focal distance is the length between the real and the geometrical focus of the ellipse.

## RESULTS

In Figure 3 it can be seen that the results obtained with the numerical model compared well with the experimental data acquired in the two transects shown in Figure 2. This validation allowed us to compute the normalized wave height and the focal distance  $D_m$  for different values of the ellipse eccentricity. From several numerical tests it was found that the wave energy amplification is not only a function of the eccentricity but also of the size of the semi-minor axis ( $b$ ) regarding the incident wave length. In Figure 4 (top) it can be seen that the maximum amplification occur when the semi-minor axis of the ellipse is one half of the incident wave length with an eccentricity of 0.954. Another maximum was obtained when the semi-minor axis was equal to the incident wave length with an eccentricity of 0.8.

## ACKNOWLEDGMENTS

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