The Study of Sea Waves as an Encouraging Application for the Teaching of Undulatory Processes

Authors:

Marcos H. Giménez, Dept. of Applied Physics, ETSID, Technical University of Valencia, Camino de Vera s/n, 46022 Valencia, Spain, mhgimene@fis.upv.es
Carlos R. Sánchez-Carratalá, Dept. of Mechanics of Continuous Media and Structures Theory, ETSICCP, Technical University of Valencia, Camino de Vera s/n, 46022 Valencia, Spain, csanchez@mes.upv.es

Abstract — *Optical devices and ripple tanks are widely used tools for the teaching of undulatory processes, but they fail to provide an easy visualization of the waves themselves and their behaviour. The development of Technologies of Information and Communication has provided tools for producing computer programs and animations that, by means of simulated sea waves, allow students to understand the nature of waves and the related phenomena, such as reflection, refraction, diffraction and interference. The implementations of these tools that we have developed and the way they focus on the underlying processes are presented. These didactic resources are complemented with real examples of sea waves interacting with the coast, coastal structures and ships, what introduces an additional motivation, since students are familiarized with sea waves as a common process in nature.*

Index Terms — *digital animation, engineering education, sea waves, simulation program.*

INTRODUCTION

Undulatory processes are one of the subjects that students of engineering have more difficulties to understand. These difficulties are made evident both in the concept of wave and in the related phenomena, such as refraction or interference. A classic method for visualizing these phenomena is by means of optical devices -laser beams, lenses, mirrors- that allow to see the rays behaviour, but not the waves themselves. Ripple tanks are also used, but their small size and the high frequency of the generated waves make the visualization difficult.

As an alternative, we have verified the didactic efficiency of the study of sea waves for the teaching of undulatory processes, since they allow to see wave fronts -instead of wave rays- in a more adequate scale than ripple tanks. Furthermore, students are familiarized with sea waves as a common process in nature, what introduces an additional motivation.

In this paper, it is shown that the manner in which sea waves interact with the coast, coastal structures and ships allows to easily visualize phenomena such as reflection, refraction, diffraction and interference. Additionally, we complement this case study with digital animations and simulation programs that show the structure of waves both in space and time. On the one hand, the digital animations of waves reproduce the different phenomena associated with undulatory processes, pointing out the basic aspects. On the other hand, the simulation programs allow the user to control the variables of the process, and subsequently to observe the behaviour of both individual oscillators and the wave as a whole; in this way, students can test how these variables affect the process, and differentiate between the oscillators motion and the wave motion. The efficiency of these computer tools in the teaching of undulatory processes has been widely proved [1].

THE NATURE OF SEA WAVES

According to the linear model (see [2], [3]), the vertical movement of the sea surface can be described as a superposition of independent harmonic components, each one of them travelling at a velocity given by the linear dispersion relationship:

$$v = \sqrt{\frac{g}{k}\tanh kd} \tag{1}$$

where g is the acceleration due to gravity, d is the water depth, and k is the wave number. As shown in Figure 1, the sea bottom scarcely affects the wave velocity when the water depth is greater than one-half of the wavelength, while sea waves travel slower when they progress in intermediate and shallow water. As we will show below, this means that sea waves are refracted by changes in the water depth.

Students usually have difficulties to differentiate between the movement of the individual oscillators and the wave as a whole. Consequently, they have problems to understand the concepts of longitudinal wave and transversal wave. These problems are even greater in the case of sea waves, that are mixed waves, that is, with both longitudinal and transversal components. Digital simulation, that allows the user to control the variables of the process and provides a visual representation of the results both in space and time, arises as a very useful tool. Figure 2 shows frames of these representations corresponding to the cases of a transversal wave and a mixed wave. The program used to generate this figure also offers the possibility of tracing the path of any individual oscillator by clicking on it. Therefore, the user can compare the behaviour of the different oscillators, and can distinguish it from the behaviour of the complete wave.

PHENOMENA RELATED TO WAVES

As any kind of wave, water waves are subjected to phenomena such as reflection, refraction, diffraction and interference (see [4], [5]). Educators have widely taken advantage of this fact by means of ripple tanks. However, the small size of these devices and the high frequency of the generated waves make the visualization difficult. In the following sections, digital animations that facilitate the understanding of the different phenomena associated to waves will be shown, as well as different examples of the interaction of sea waves with the coast, coastal structures and ships.

Reflection

When a sea wave train encounters a vertical wall, the imposed boundary conditions require the reflection of waves to be satisfied. In the case that all of the energy is reflected, the result is a standing wave. Figure 3 shows a frame of an animation designed to visualize the case of reflection when the incident wave travels obliquely to the wall. The resulting sea state presents propagation in the direction parallel to the wall, while standing waves appear along the perpendicular direction. Lines on the sea surface in both directions are also shown in the figure.

The reflected waves generated by a structure may propagate some distance, and become a source of disturbance in areas of a harbour that otherwise would stay calm. Furthermore, these waves cause a greater agitation in front of the structure, as shown in Figure 4. The breaking wave on the left of the photography is a reflected wave, as proved by the fact that it is breaking in the seaward direction.

Refraction

As mentioned above, the velocity of sea waves depends on the water depth. Therefore, a change of depth is equivalent to a change of medium in the case of other kind of waves. Ripple tanks take advantage of this fact by placing pieces that suddenly change the local depth. Figure 5 shows frames of animations based on the same effect, but designed for providing an easier visualization than ripple tanks do. The first animation presents a perspective of the process, including two individual oscillators that prove that the period remains the same, while the wave fronts allow to notice the changes of wavelength and wave velocity. The second animation shows the corresponding top view, usually used in static illustrations of wave refraction.

In the sea, the changes of water depth are not sudden, but gradual. Therefore, changes of direction are gradual too. When sea waves approach a bottom slope obliquely, the portion in shallower water travels more slowly than that in deeper water according to (1). Therefore, wave fronts tend to become more closely aligned with the bottom contours. This fact, illustrated by the photography in Figure 6, explains why sea waves in beaches are nearly parallel to the coast.

Diffraction

When sea waves encounter a barrier, they pivot around the edges of the obstacle and penetrate into the region of geometric shadow by the process of diffraction. This phenomenon can be easily generated in ripple tanks, using different configurations of barriers and gaps. Figure 7 shows a frame of an animation corresponding to the case of a wave train intercepted by a barrier with a gap that acts as a source of circular waves. It can be noted that the amplitude of these simulated waves remains constant, in spite of the fact that this amplitude should decrease with the square root of the distance to the source. This disagreement with respect to the real behaviour is pointed out to the students, and justified as a previous step for an easier visualization of the phenomenon of interference, as will be described below.

Diffraction of sea waves is a process of considerable practical importance in the study of the wave action behind breakwaters and around offshore structures, conditioning the layout of harbour entrances in order to reduce agitation in the inner basins to acceptable levels. Figure 8 illustrates the way a sea wave train diffracts around the edge of a breakwater, and penetrates into the sheltered area.

Interference

As any kind of waves, two sea wave trains interfere while they travel through the same medium. This phenomenon can be generated in ripple tanks by using a barrier with two gaps, providing a good visualization of the result, but a poor understanding of the underlying process. This lack can be covered by means of digital animations, such as the ones shown in Figure 9, that focus on the way the two wave trains interact. The individual oscillators have been positioned in such a way that the superposed wave trains make them to oscillate either in phase or in opposition, as the first animation shows. The second animation presents the composed movement, where these individual oscillators are antinodes or nodes respectively. Finally, the third animation shows the behaviour of the sections along the wave fronts (ellipses) and along the rays (hyperbolas). An important aspect in this set of digital animations is that the represented amplitude of the superposed wave trains does not decrease when they move away from their sources. A more realistic implementation would result in a more difficult visualization of the process far from the barrier. Therefore, the amplitudes remain constant for obtaining a better understanding.

Figure 10 illustrates a real case of interference of sea waves. The diffracted swell waves around the bow and the stern of the ship interfere on its port side according to a typical interference pattern. On the starboard, a different but more confusing diffraction pattern can be observed.

CONCLUSIONS

While optical devices allow to see the rays behaviour of undulatory processes, ripple tanks are used to see the waves themselves, though their small size and high frequency make the visualization difficult. Simulation programs, that allow the user to control the variables of the process and provide a visual representation of the result both in space and time, make it easier to understand the behaviour of individual oscillators and the wave as a whole. Digital animations of sea waves facilitate the visualization of the phenomena associated to the waves –reflection, refraction, diffraction and interference- when compared to ripple tanks, including the underlying process. Additionally, related examples of interactions between sea waves and the coast, coastal structures and ships are shown for the purpose of encouraging students in the learning of these processes.

REFERENCES

[1] Giménez, M.H., Riera, J., Vidaurre, A., and Salinas, I., "Las Nuevas Tecnologías aplicadas a la enseñanza de los procesos ondulatorios", *Proc. VIII Congreso de Innovación Educativa en las Enseñanzas Técnicas,* San Sebastián, Spain, Vol. 2, 2000, pp. 67-77.

[2] Kinsman, B., *Wind waves,* Dover Publications, New York, NY, 1984.

[3] Silvester, R., *Coastal Engineering,* Elsevier Scientific, Amsterdam, The Netherlands, 1979.

[4] Goda, Y., *Random seas and design of maritime structures,* University of Tokyo Press, Tokyo, Japan, 1985.

[5] Sarpkaya, T., and Isaacson, M., *Mechanics of wave forces on offshore structures,* Van Nostrand Reinhold, New York, NY, 1981.

FIGURES AND TABLES

FIGURE 1
DEPENDENCE OF SEA WAVE VELOCITY ON THE WATER DEPTH.

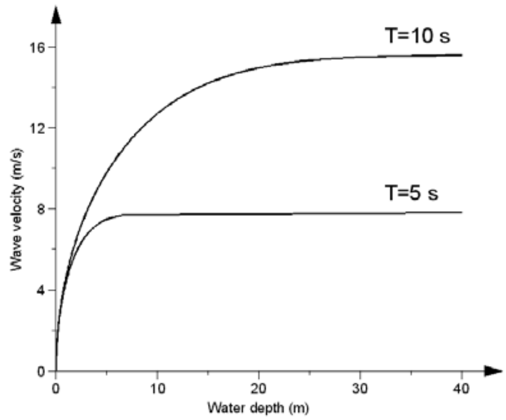

FIGURE 2
DIGITAL SIMULATION OF THE BEHAVIOUR OF INDIVIDUAL OSCILLATORS FOR A TRANSVERSAL WAVE (LEFT) AND A MIXED WAVE (RIGHT).

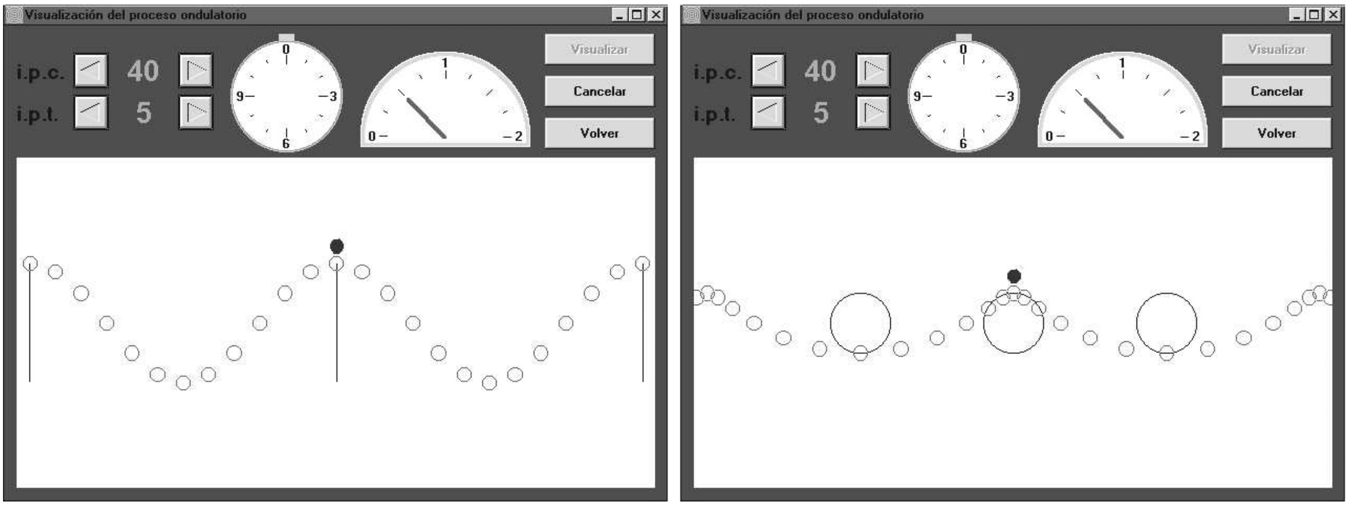

FIGURE 3
DIGITAL ANIMATION OF THE REFLECTION OF A SEA WAVE TRAIN INCIDENT OBLIQUELY TO A VERTICAL WALL.

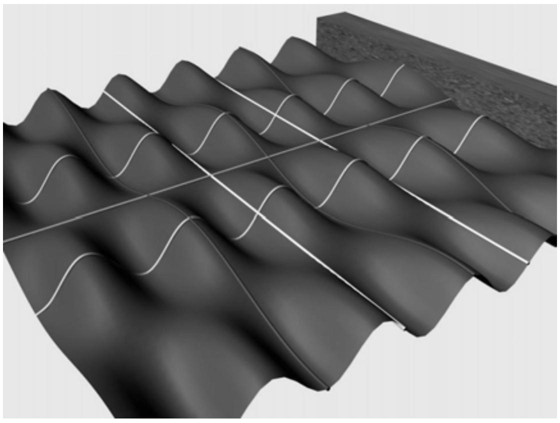

FIGURE 4
INCREASE OF THE AGITATION IN FRONT OF A SEAWALL, CAUSED BY THE SUPERPOSITION OF THE INCIDENT AND REFLECTED WAVES.

FIGURE 5
DIGITAL ANIMATIONS OF THE REFRACTION OF A SEA WAVE TRAIN CAUSED BY A SUDDEN CHANGE OF THE WATER DEPTH, IN PERSPECTIVE (TOP) AND IN A TOP VIEW (BOTTOM).

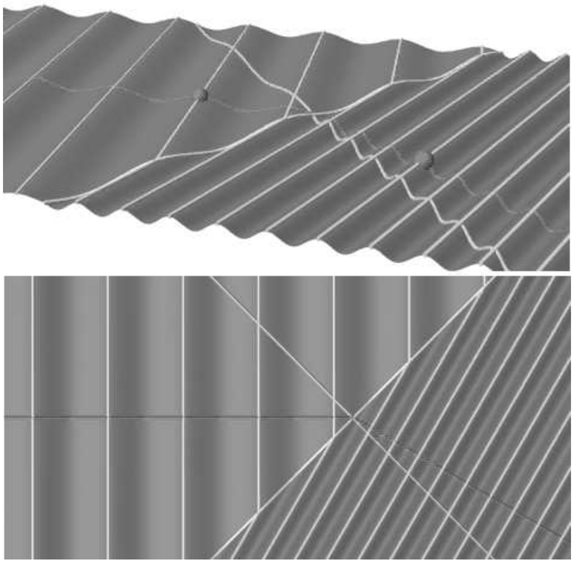

FIGURE 6
WAVE FRONTS THAT, DUE TO REFRACTION, BECOME MORE CLOSELY ALIGNED WITH THE BOTTOM CONTOURS AS THEY TRAVEL TOWARDS THE BEACH.

FIGURE 7
DIGITAL ANIMATION OF THE DIFFRACTION OF A SEA WAVE TRAIN THROUGH A GAP IN A BARRIER.

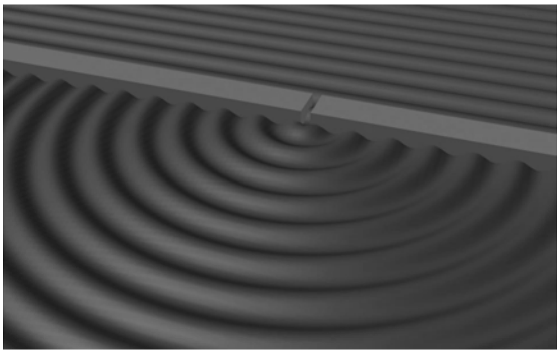

FIGURE 8
SEA WAVE S THAT, DUE TO DIFFRACTION AROUND THE EDGE OF A BREAKWATER, PENETRATE INTO A SHELTERED AREA.

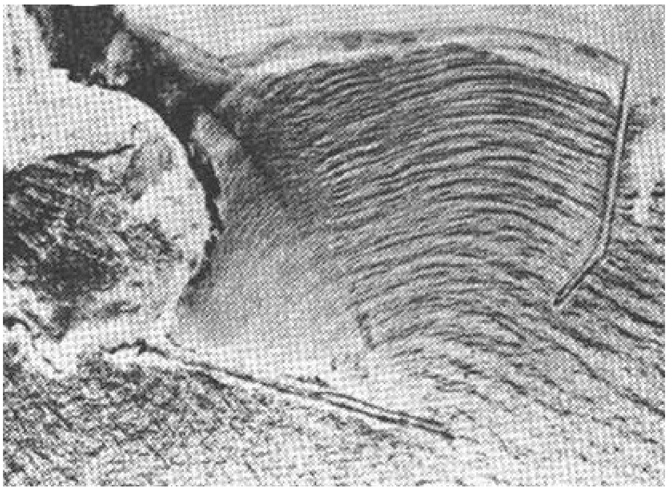

FIGURE 9
DIGITAL ANIMATIONS OF A SEA WAVE TRAIN DIFFRACTING FROM TWO GAPS IN A BARRIER (TOP) AND THE RESULTING INTERFERENCE (MIDDLE AND BOTTOM).

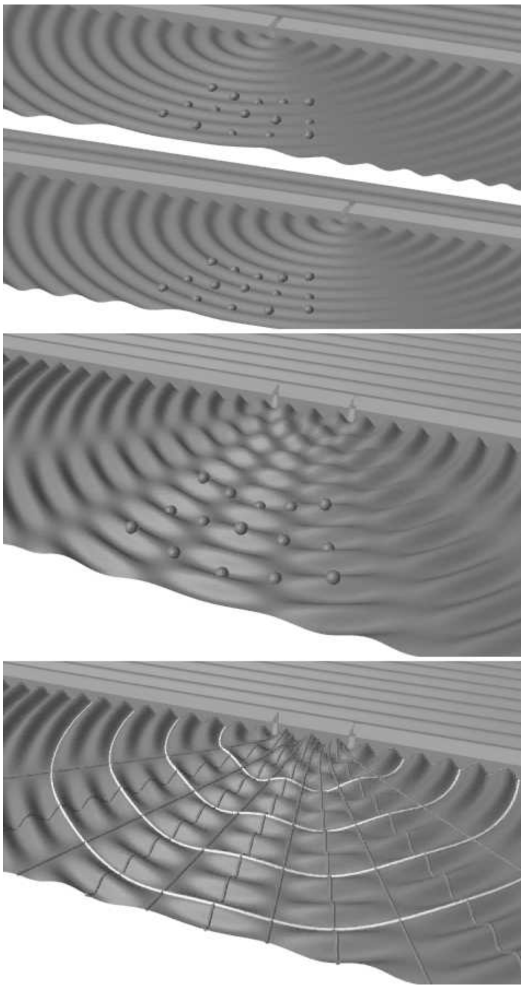

FIGURE 10
INTERFERENCE PATTERN ON THE PORT SIDE OF A SHIP DUE TO DIFFRACTION OF SWELL WAVES AROUND ITS ENDS.