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FLUID CONTROL BY ACOUSTIC META-LENS ARRAY

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A removable fluid control wall by array of acoustic Eaton lenses is proposed theoretically. The rotating property of the lens reduces the pressure of water wave by the tsunami against tsunami method. Impedance matching at the wall produces no reflection. The diameter of the lens should be larger than that of tsunami nearest coast or order of km. A model of acoustic Eaton lens is designed by a variable density method. The lens is composed of multi-hundreds of expandable rubber balloons. Before a tsunami, the balloons are buried underground in the shallow water near coast in folded or rounded form. Each balloon is connected to rubber pipes underground. On the alarm of a tsunami, water and air are pumped into the balloons to expand and erect the lenses to the sea level within in a few hours. After the tsunami, the water and air are pumped out from the balloons, and then are buried back to the underground for reuse.

1. Introduction

A tsunami is a series of large tidal waves or waves heading towards the coast. Tsunami's commonly are accompanied if an earthquake occurs within the ocean, and it is usually far greater than the damage caused by an earthquake in the event of both together. As the tsunami travels and enters the shallow water in the coastal area, the speed of the tsunami is slowed down and its wavelength is shortened in km, but the amplitude grows enormously. Since the wave front becomes parallel to the coastline, it can be approximated as a plane wave near the coast. When a water wave comes into the shore, the vertical height above sea level to which it rises is called the run-up. The high run-up of the multiple waves together with a long inundation distance of the tsunami make it one of the most devastating ocean disasters. Maximum wave heights of tens of meters can be generated by large events.

The main factor of tsunamis damage comes from the smashing force and the destructive power by high pressure of a large volume of water. It is extremely difficult for a hard wall to withstand the huge momentum of a tsunami. A concrete wall doesn't guarantee the safety of the coastal infrastructures behind the wall. A combination of smashing forces and pressures poses serious damage to the stability of the wall. The heavy weight of the wall may produce a serious subsidence of ground. The wall is a biological separation and an obstacle of human and animal passage. A large tsunami occur only once per decade in most coastal areas. Therefore, it is inefficient and anti-environmental. In fact, previous studies on tsunami's are quite extensive, but the method of protection for those on the event beyond the wall method is very rare.

In this study we suggest a theoretical proposal of a removable rubber-made tsunami wall based on a gradient index (GRIN) lens technology originated from optics. It is a tsunami-against-tsunami method with an array of flexible acoustic Eaton lenses (AEL), which has a wave rotation property without reflection by impedance matching.

2. Acoustic Eaton lens array

The the refractive index (RI) of GRIN lenses is given as a function of the radius and there is no reflection by impedance matching. Eaton lens is a GRIN lens in which the RI varies from one to infinity. It is an analogue of Kepler's scattering problem, which is derived from the relation between the light trajectory and its RI at any impact parameter [1]. It has a singularity in which the RI goes to infinity at the center of the lens and the speed of light is reduced to zero at this point. Therefore, the lens can change the wave trajectories any direction [2].

The RI of the Eaton lens at 180 degree of refraction angle is given by Eq. (1) [3, 4].

$$n = \sqrt{\frac{2a}{r} - 1}, \tag{1}$$

where a is the radius of the lens, and r the distance to the center. Note that $n = 1$ for $r \geq a$. It is a kind of mirror that the incident wave returns to the original direction without phase difference [**?**]. The rotating property of Eaton lens appears regardless of its oscillating direction to that of the energy transfer.

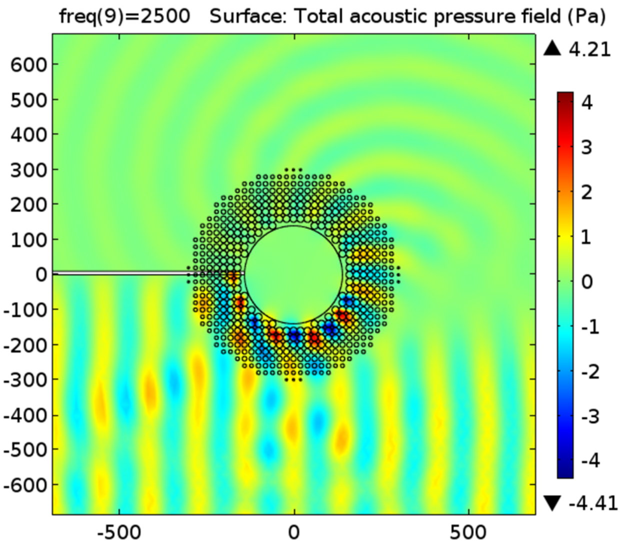

Figure 1: Rotating property of the designed acoustic Eaton lens by numerical simulation. Plane wave of 2,500 Hz was sent from the left. The unit of x-axis is mm.

An acoustical analogy of the Eaton lens is the key of the wall. A model of a two-dimensional AEL is designed by variable density method. The wave equation of the acoustic counterpart is governed by the density and bulk modulus or the inverse compressibility of the medium. The background speed of a sound wave is $v_o = \sqrt{B/\rho_o}$, where B and ρ_o are the background bulk modulus and density outside the lens, respectively. The modulus is assumed to be constant. Therefore, the variable density method is applied as

$$n(r) = \frac{v_o}{v(r)} = \sqrt{\frac{\rho(r)}{\rho_o}}. \tag{2}$$

The refractive index in Eq. (1) is digitalized and matched with in Eq. (2) as

$$\frac{2N}{i - 0.5} - 1 = \frac{\rho_i}{\rho_o}, \tag{3}$$

where i=1,... N.

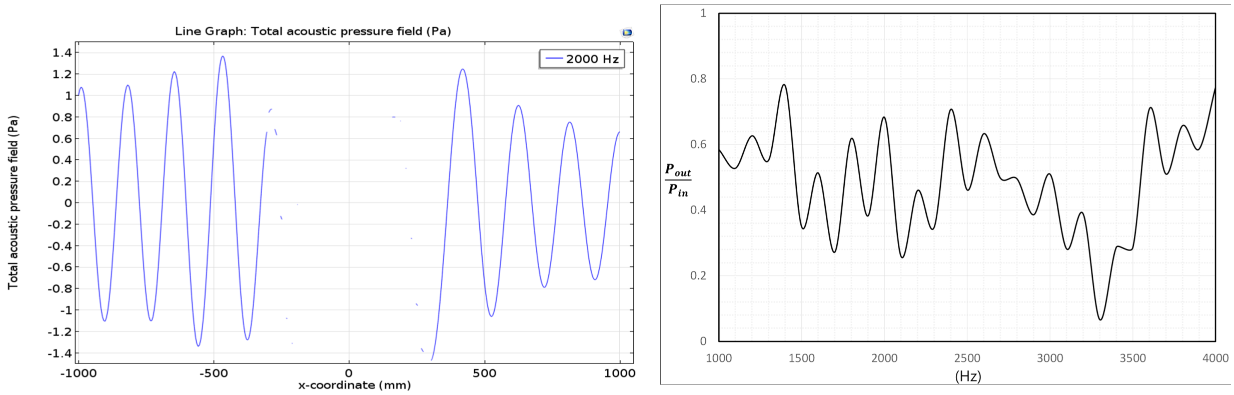

Figure 2: Left: Acoustic pressure just before and after an Eaton lens. Right: Frequency dependent pressure ratios between input and output waves.

Numerical simulations of the designed acoustic Eaton lenses are shown at Fig. 1. N=15 was chosen in Eq. (3). R=30 cm and the distance between pillar is 2 cm. If we send out arbitrary waves towards the Eaton lens, the trajectories of the waves are overlapped with different directions and reduce the intensity [5]. The RI has a singularity at the center or $r = 0$ in Eq. 1. It is a cut at some point in design and the part becomes a large single cylinder in the center. Our choice of the cut was the half of the radius, but it makes the impedance matching incomplete. The diameter of the center circle is approximately half that of the lens. Beyond the center, the 488 circular pillars of the diameter between 19 mm and 6 mm are radially located. The number of the pillars is adjustable. The more the pillars, the better for the rotation and the impedance matching, but more expensive to build. The output pressure becomes one half that of the input pressure after passing through just one AEL on the average as Fig. 2. Therefore, a double array of Eaton walls will reduce the output pressure about one quarter. Waves of short wavelength pass the lens but it is not dangerous,

3. Tsunami Lens Engineering

The tsunami wall is the AEL array. Each pillar of the AER is a rubber balloon in fields. The height of the balloon is order of average tsunami height, that is, 10$\sim$20 m above the sea level. Note that the height is about 1 % of the diameter. Therefore, the AEL is flexible and stable from tsunami attack. The wave-against-wave method is converted into a tsunami-against-tsunami method. AEL is made by expandable rubber balloons and buried underground in the shallow water near coast in folded or rolled form. The diameter of the AEL should be larger than that of the tsunami near the coast or km because it rotates the waves of wavelength smaller than its diameter. The distance between boundaries of the lenses must be smaller than the wavelength of the tsunami or order of km.

The tsunami wall is the array of AEL which is shown in Fig. 3. The 2+2 two-layer Eaton wall reduces the pressure into one quarter. There could be many formations of wall by AEL [4]. The tsunami wall comprises AEL arrays that are made from expandable rubber pillars or balloons. The pillars are buried underground in shallow water near the coast in a folded or rolled form. The large center region is divided into many rubber pillars and held together by ropes. Before alarming of tsunami, the walls are buried underground in the shallow water near the coast in folded or rounded form. Each balloon is connected to rubber pipes under the ground for pumping up water and air. On the tsunami alarm, we pump water and air into the AEL by the pipes to erect it up above the sea level. The AEL puffs up like rubber balloons. After the tsunami, the water and air are pumped out of the balloons which then are buried back to the underground for reuse next time. The entire process is operated by electric power.

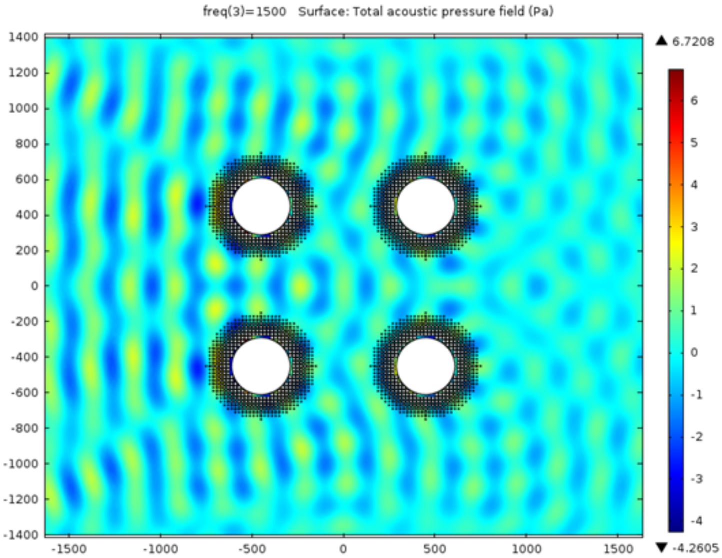

Figure 3: Numerical simulation of the 2+2 acoustic Eaton lens array. f=1,500 Hz. The unit of x-axis is mm.

4. Summary

A removable tsunami wall of the array of acoustic Eaton lenses was proposed theoretically. It is a wave-against-wave cancelation by the impedance matching and wave rotating property of AEL. A model acoustic Eaton lens was designed by a variable density method. The pressure reducing property of the lens with little reflection by the impedance matching was simulated by computer. One lens reduces the input pressure into about one half. The diameter of the lens should be larger than that of the tsunami or mostly order of km. Before the tsunami comes, there is nothing above the sea level. When the alarm of a tsunami is approaching, the tsunami wall is built in a few hours by electric power. The wall reduces the water pressure of the tsunami. After the tsunami, the wall disappears by electric power and then the sea backs to scene before the tsunami alarming.

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