Numerical Evaluation on Tank Effect in a Pseudo-Scale Air-Sea Two-Layer Experimental Model

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***Abstract*— The effect of existence of a tank in the pseudo-scale model experimental system is investigated by numerical simulation using the FDTD method. Comparison of simulation results for three models including with-tank and no-tank models, confirms that there is no effect of the tank on the electric field distribution at the sea surface, except near the tank wall. It is also observed that raising the water level and decreasing the air volume inside the tank can slightly reduce the effect of the electric field in the air penetrating the tank wall.**

Keywords*— *Air-sea two-layer problem, pseudo-scale model, effect of tank wall, FDTD simulation.

I. Introduction

The authors have investigated an underwater position estimation system for divers using electromagnetic waves to assist divers' rescue activities in the event of a water accident [1]. Since experiments in the sea are costly, the authors propose to introduce a pseudo-scale model into the underwater position estimation model [2]. To apply the experimental results obtained from the pseudo-scale model to underwater position estimation [3], the effect of the tank must be evaluated in advance. To investigate the effect of tank, this paper presents numerical results for the air-sea two-layer problem with and without tanks on an experimental system for a pseudo-scale model.

II. With-Tank and No-Tank Configrations

The original model for underwater location estimation assumes a 50 m × 50 m × 9 m sea area. Buoys equipped with receiving dipole antennas are placed at equal intervals on the sea surface, and divers are equipped with transmitting dipole antenna [4]. The frequency of the original model is 10 kHz.

Fig. 1 shows the experimental system for the pseudo-scale model with scale factor $n = 200$ [4]. Upon pseudo-scale conversion, the converted length is $1/n$ times the original length, and the converted frequency is n^2 times the original frequency. The real part of the complex permittivity and conductivity of seawater remain unchanged before and after the scale conversion [2]. And we assume that the tank is made of glass with a thickness of 5 mm and has dimensions of 915 mm × 460 mm × 305 mm.

Fig. 2 shows a cross-sectional view parallel to the xz plane of the simulation model with the tank wall including the air region outside the tank wall, for the experimental water level and full water level. To obtain numerical results that more closely resemble the corresponding experimental environment, simulations are performed using a model that includes the air region outside the tank walls. In our FDTD simulations, we model a cubic region of 600 mm per side for only the left side of the water tank where the receiving antenna is located in the experimental setup for the pseudo-scale model as shown in Fig. 1. For simplicity, only the tank, air, seawater, and transmitting antenna are modeled. The real part of the complex relative permittivity of the tank and seawater are set to 4 and 80, and the conductivity of the tank and seawater are set to 0 S/m and 4 S/m. An electrical dipole antenna is 10 mm long, oriented in the x direction, immersed at a depth of 20 mm below the sea surface, and excited by a continuous wave of 400 MHz.

In the experimental tank model, which means a with-tank model for the experimental water level, as shown in Fig. 2 (a), the water level from the bottom of the tank was set at 200 mm, the same as in experiments [4]. Moreover, the separation between the tank wall and absorbing boundary is set to 70 mm. In the full tank model, which means the with-tank model for the full water level, as shown in Fig. 2 (b), only the water level is raised to 300 mm, the same as the height of the tank, to check the effect of the air portion of the tank. In the no-tank model, the tank wall of the with-tank model are replaced by seawater and air above and below the sea surface, respectively.

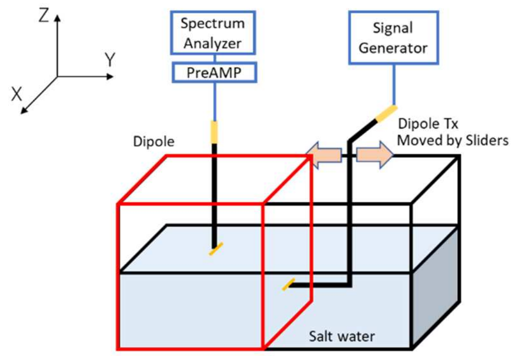
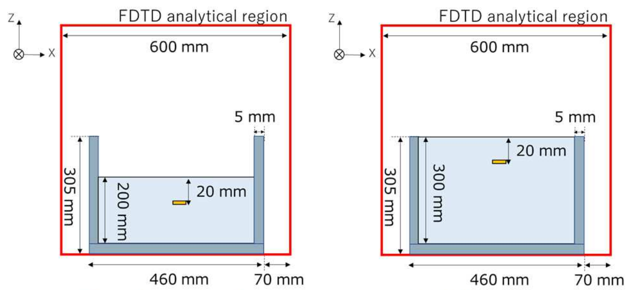


Fig. 1. An experimental setup for pseudo-scale model of air-sea two-layer problem.



(a) Experimental-tank model (b) Full-tank model

Fig. 2. Two "with-tank models" which are air-sea two-layer simulation models including tank wall with two different water levels.

III. FDTD Simulations Results for With-Tank and No-Tank Models

Fig. 3 shows the $|E_x|$ distributions on the xz plane for two with-tank models and non-tank model. Note that the sea surface is commonly located at $z = 0$ mm. All three models show exponential attenuation around the transmitting dipole antenna in the sea region, except near the sea surface. In the sea near the surface, nulls of lateral wave are observed in the vicinity of the antenna [2]. In the air region, dipole antenna radiation centered at $x = z = 0$ mm can be observed, with a much smaller decrease in amplitude than in the sea region. For $|x| < 150$ mm and $z > -180$ mm, there is little difference in the electric field distribution among the three models. As can be seen in Fig. 3 (a) and (b), the electric field distributions in the tank-models can be affected by the tank wall for $|x| \geq 150$ mm and $z \leq -180$ mm. This is because the electric field in the air region propagates along the tank wall and affects the electric field near the tank wall in the seawater region.

Fig. 4 compares the $|E_x|$ distributions along the x-axis for the three models. The distributions for the experimental- and full-tank models plotted by the solid red line and dotted blue line are consistent with that for the no-tank model plotted by the solid black line for $|x| \leq 125$ mm and $|x| \leq 200$ mm, respectively. This confirms that the full-tank model is closer to the no-tank model than the experimental-tank model. For the $|E_x|$ distribution for 225 mm $\leq |x| \leq$ 230 mm, which corresponds to the tank wall region, the values of $|E_x|$ for the two with-tank models are not consistent with the value for the no-tank model. There is no difference between the experimental- and full-tank models so that the water level cannot be a critical parameter to measure $|E_x|$ in the large portion of the measurable range along the x-axis. The above simulation results show that even if the air region outside the tank wall is included in the simulation area, the effect of the tank wall can be observed only in the very close vicinity of the wall.

IV. Conclisions

The effect of tank on the experimental system for the pseudo-scale model is examined by comparing the numerical results using the FDTD method among the two with-tank models and no-tank model, whether or not the air region outside the tank is included. The electric field distribution on the sea surface where the receiving antenna is placed in the experiment shows that the effect of the tank wall cannot be observed except very close to the wall surface. It is also found that by the effect of the electric field transmitted along the tank wall in the air region can be slightly reduced bringing the water level closer to the height of the tank and reducing the air region inside the tank.

Acknowledgment

This research was supported in part by JSPS KAKEHI Grant Number JP20K04496.

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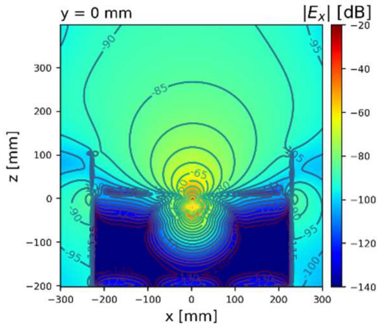
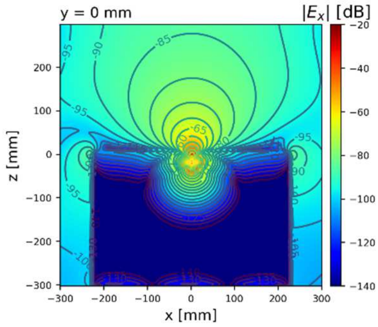
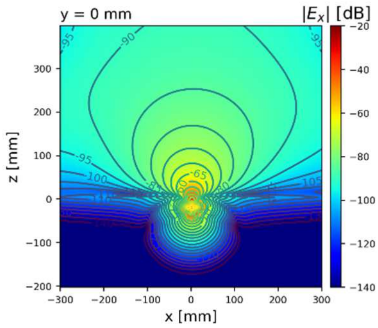


(a) Experimental-tank model



(b) Full-tank model



(c) No-tank model

Fig. 3. $|E_x|$ distributions in the xz plane for two with-tank models and no-tank model including the contribution of the air region outside the tank.

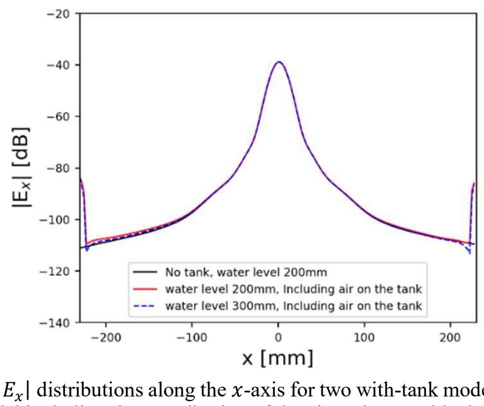


Fig. 4. $|E_x|$ distributions along the x-axis for two with-tank models and no-tank model including the contribution of the air region outside the tank.