Purification of Contaminated Water by Tidal Energy
– Purification of a Fresh Water Lake –

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An artificial fresh water lake may be made after the reclamation of an intertidal flat at the mouth of a river. When the reclamation is completed and the breakwater is closed, the flow of the water in the lake is significantly reduced. Especially, the bottom water is stagnated and strong stratification of the water quality begins. Thus, the fresh water in the lake is easily polluted because of the strong stratification in it. In order to preserve the quality of fresh water in the lake, we suggest a novel method of water purification by using Utsuro which is a water area enclosed by a permeable embankment. Originally, Utsuro utilizes change of water level due to tide. However, in case of the fresh water lake mentioned above, the water level does not change since the breakwater is shut to prevent the inflow of sea water. Two new Utsuro systems proposed by us solve this problem. One is using an inflatable bag on the seabed within Utsuro while the other is using a moored floating barge out of dyke. In short, equalization of water level between Utsuro and sea out of dyke or between Utsuro and the barge changes water level in Utsuro and makes water flow through the permeable embankment of Utsuro. The flow through the vacancy between stones and rocks in the embankment of Utsuro reduces the water pollution by utilizing biological effect. The purified water spreads over the artificial lake, and the quality of the water in the lake is improved. It may contribute to avoid the disastrous pollution of the fresh water in the lake. In the paper, the basic concept study is introduced. If we replace the fresh water lake with the contaminated water reservoir, the same principle applies to the purification of contaminated water.

Key Words : Contaminated Water, Water Purification, Fresh Water Lake, Reclamation, Utsuro

1. Introduction

In order to tackle with water pollution and eutrophication due to contamination by a great amount of pollutant effluent from the land, there are several methods on sea water purification system. One of the promising methods is the self-purification system which consists of permeable rockfill embankments such as rubble seawall. We call it as “Utsuro”. The term “rubble” used here includes rock and riprap. The Utsuro has also similar function of a rubble mound breakwater by Palmer[1] to protect a coastal area from excessive wave. The Utsuro means a calm space enclosed by permeable embankment. In this paper, we try to suggest the Utsuro for water purification of the reclamation area. Due to the reclamation, sea water is not allowed to flow into the lake and the water level of the lake does not change because of breakwater. This situation invites the degradation of water quality in the lake. It is utmost important to keep the quality of the fresh water in the lake.

As for the bio-function of the Utsuro, the surface of the rock in the rockfill embankments plays a role of the biofilms in which many marine microbes live. Oxidized dismantling of an organic matter and decomposition of the nitrogenous and phosphorus occur at the surface as the basis of the biological process. Ocean benthos and seaweeds take part in the food chain so that the rock filter effect shows not only lower COD(Chemical Oxygen Demand) and higher DO(Dissolved Oxygen) but also more photosynthesis. The aeration of breaking wave gives the amount of contact oxidation into the rockfill enhances the function of seawater purification.

Several researchers have studied on the function of the “Utsuro” in physical[2,3], ecological[4,5], experimental since the concept starting from 1981 by K. Akai[6]

For example, the quality of the water is improved on the several parameters: 0.56 to 0.2mg/l for turbidity, 4.64 to 3.7mmg/l for COD and 6.06 to 4.61mg/l for SS (Suspended Solid) measured by [3] in and out of the Utsuro settled at Osaka bay in 1990. This effect may also be expected after installation of the Utsuro at the fresh water lake[6].

In 2001, Utsuro was constructed at the estuary of Kinokawa, Wakayama, Japan to improve the water quality in the region. The area of Utsuro is about 30,000m^2 and tidal height is about 1.5m so that the capability of purification will be 90,000ton per day approximatly. Transparency in Utsuro is about two times bigger than its outside of Utsuro[7].

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On aeration effect as the seawater passes through the rockfill embankment, Horie[8] discussed that it increases with decrease of the reflection of waves which depends on the surface roughness and slope angle of the breakwater.

2. Korea's representative reclamations

2.1 Lesson from Shihwa Lake

Lake Shihwa is an artificial lake located on the west coast of Republic of Korea. The construction of the breakwater with length 2.6km had been completed in 1994. A Korean government plan aimed at creating 133.7km^2 of reclaimed land and 42.3km^2 of a freshwater lake to be used for irrigation purpose. When the freshwater lake was closed off, they began to build two industrial complexes and a new city in the northern part of the lake. Due to the insufficient water supply to the lake, the lack of wastewater treatment capacity and the increasing pollution load from the pollutors, the brackish lake suffered from severe eutrophication 17.4 mg/l of annual mean COD(Chemical Oxygen Demand) in 1997. Finally, late in 2000, lake Shihwa was changed to a seawater lake rather than fresh water resources for the farmlands. Annual mean COD concentration of lake Shihwa decreased to 4.2 mg/l in 2005 and is expected to recover 2.0 mg/l of COD in 2010. Sewage treatment facilities has been constructed and expanded in order to make the water exchange in the lake improve via operation of barrage sluice. Shihwa tidal power plant has been constructed to increase seawater circulation, which is the most efficient measure for improving water quality and restore its ecosystem for sustaining Shihwa Lake that is not the reclamation site furthermore.

2.2 Saemangeum reclamation

Saemangeum reclamation is the world's largest coastal reclamation which constructs seawall with length 33km, reclaimed land with area 283km^2 and freshwater lake with area 118km^2. It is located near estuary of two rivers Mankyong and Dongjin. After coffering completed in 2006, the internal development is promoted until 2020. At the beginning stage, 62% of the reclaimed land is planned to be allocated for agricultural use, 22% for public use, and 13% for industrial parks. Recently, new complex economic hub including international business, environment and energy complexes is added in the reclaimed land so that the field for rice production is reduced to about 30%.

There are two sluice gates which are consisted of Garyeok 8 flaps(287.5m) and Shinsi 10 flaps(368.5m). The flow rate is about 7,000ton and 8,800ton per second for each gate. One way-pipe line is settled under the gate in order to tackle with an accumulation of high saline water on the seabed in the fresh water lake.

The agonizing experiments of the lake Shihwa have made this Saemangeum project to be seriously considered by decision of political plan at the end of 1990s. As part of an effort for increasing environmental quality and encouraging environmental friendly development, Saemangeum project is proceeding in a different way than the lake shiwha. Table 1 shows results of efforts at the management of water quality in the Saemangeum region.

Tab.1 History of water quality at the mouth of Mankyong River in Saemangeum region(source : JICE Report, 2006[9])

	98	99	00	01	02	03	04
BOD[1)]	6.8	7.1	6.8	6.8	5.6	3.7	4.1
T-P[2)]	0.607	0.608	0.537	0.689	0.484	0.364	0.391

1) Biological Oxygen Demand
2) Total phosphrus

3. Two Suggested Utsuro Applications

Utsuro means vacant space in Japanese. Utsuro in the present paper is the space in ocean surrounded by the rubble mound breakwater so that the water can flow in and out Utsuro through it. Contaminated costal seawater can be purified by biofilms where bacteria and protozoan live in the surface of the rock used for the breakwater immersed in water.

Tab.2 Comparison on outside (before penetration) and inside (after penetration) of the Utsuro at the downstream of the Yellow River(2008. 3)[6])

Contents	Outside of Utsuro	Inside of Utsuro	Effects
pH	7.8	7.2	-
Salty(%)	3.0	3.0	-
COD(mg/l)	2.0	1.1	45%
SS(mg/l)	4.2	<1	76% removed
Turbidity	5.0	1	Decreased to 20%

By installing the Utsuro at the downstream of the Yellow River, the value of SS and turbidity is largely improved, because of calm circumstance within Utsuro compared with outside of it. The value of turbidity and SS are shown in Table 2.

In this paper, we propose two types of new Utsuro systems for the purification at the reclamation area[10]. In these methods, in order to force the water circulation in the region necessary for purification, tidal energy is utilized.

3.1 Purification method by inflatable bag in Utsuro

Firstly, in Fig.1(a), the suggested system in a plan view consists of a submerged inflatable bag which is not permeable and settled down at the bottom of the Utsuro. A pipe line is connected from sea side to the bag. Tide flows into the pipeline, and the bag is swelled by sea water in high tide. The level of water in the Utsuro ascends, and the water level inside the Utsuro becomes higher than the water level outside. The higher water level inside the Utsuro causes the flow outward through the embankment of the Utsuro and vise versa during two tides per day. Sea water and fresh water is separated because the inflatable bag is swelled up and down by incoming and outgoing of the sea water. “F” and “S” refer to fresh water and salt water. Fig.1(c) and (d) show the principle of the system by tide. Higher tidal difference seems to make larger flow exchange through the rubble so that we may expect good purification by Utsuro.

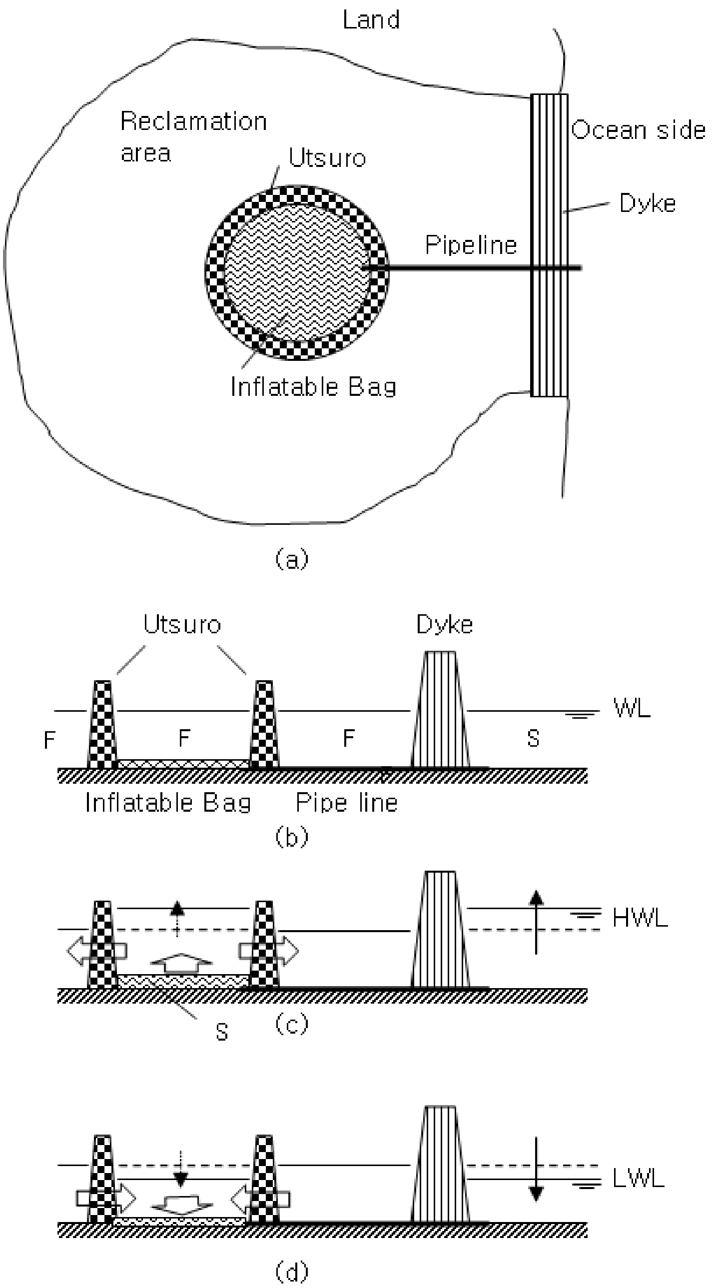


Fig.1 A schematic view of a suggested system used by Inflatable bag in Utsuro (F: Fresh water, S: Sea water)

3.2 Purification method by floating body

The second suggestion is to use the tidal difference, as shown in Fig. 2(a): plan view of the system. In this, we place a float at sea and connect with pipe the Utsuro in the lake and the float. There is no inflatable bag like in the suggestion 1. Then, the level of the surface in the Utsuro and that in the float would be equal. Furthermore, the level of the surface inside and outside the Utsuro would also be equal. So, when the float goes up due to the tide, the water flows from the float to the Utsuro, and the water in the Utsuro moves toward outside the Utsuro through the bank of the Utsuro as shown in Fig. 2(c). When the float goes down, the water flows from the Utsuro to the float, and the water outside the Utsuro moves toward inside the Utsuro through the bank of the Utsuro as shown in Fig. 2(d).

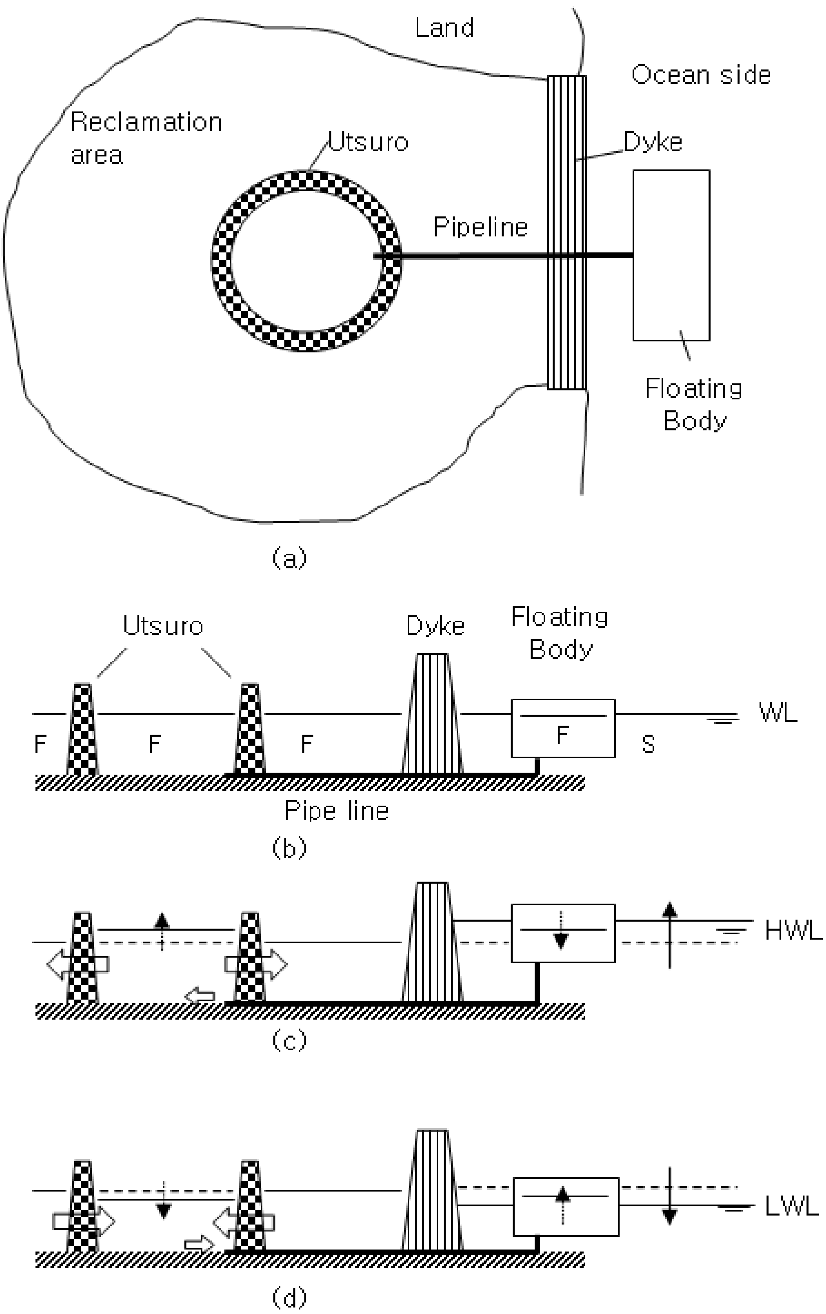


Fig.2 A schematic view of a suggested system used by a floating body out of the dyke (F: Fresh water, S: Sea water)

In the following, an example of water flow between Utsuro in a fresh water lake and floating body in the sea is discussed. A suggested system using a floating body is shown in Fig. 3. Let D_0 and D_1 be the water depth in the lake and sea, respectively.

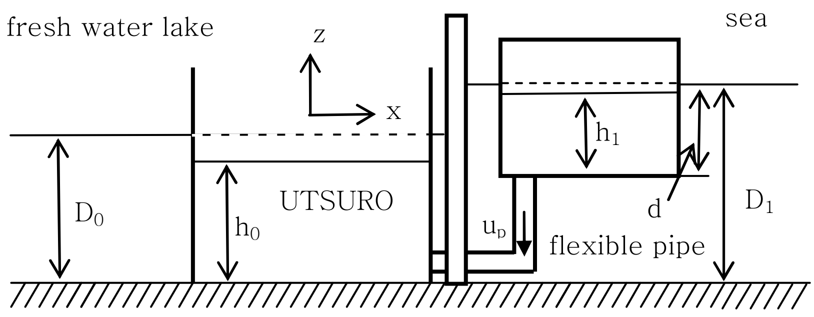


Fig.3 A suggested system using a floating body

D_1 is given by tide:

$$D_1 = D_m + A\sin\left(\frac{2\pi}{T}t\right), \tag{1}$$

where D_m, A, T and t are the mean depth of water at sea, amplitude of tide, period of tide and time, respectively.

When $D_1 - d + h_1 > h_0$, we obtain by applying Bernoulli's equation

$$\frac{1}{2}\rho_F u_p^2 + \rho_F g h_0 + \frac{1}{2}\rho_F \mu u_p^2 = \rho_F g(D_1 - d + h_1), \tag{2}$$

where g, ρ_F, μ, u_p, h_0, h_1 and d are the gravitational acceleration, density of fresh water, frictional coefficient of pipe flow, flow velocity in the connecting pipe, water depth in utsuro, water depth in float and draft of float, respectively. From Eq. (2), u_p is obtained as

$$u_p = \sqrt{\frac{2g}{1+\mu}|(D_1 - d + h_1) - h_0|}. \tag{3}$$

Hence, the governing equations are given by

$$g(M_1 + \rho_F h_1 S_1) = \rho_S g d S_1, \tag{4}$$

$$u_p = \mathrm{sgn}((D_1 - d + h_1) - h_0)\sqrt{\frac{2g}{1+\mu}|(D_1 - d + h_1) - h_0|}, \tag{5}$$

$$S_0\frac{dh_0}{dt} = u_p S_P - \alpha\,\mathrm{sgn}(h_0 - D_0)\sqrt{2g|h_0 - D_0|}, \tag{6}$$

$$S_1\frac{dh_1}{dt} = -u_p S_P, \tag{7}$$

where M_1, S_1, ρ_S, S_0, S_P and α are the mass of float, water surface area of float, density of sea water, water surface area of utsuro, cross sectional area of connecting pipe and permeability coefficient of dike, respectively. Eqs. (4), (6) and (7) are the vertical force equilibrium of the float, mass balance of utsuro and that of float, respectively. Since, the period T of tide is very long, the inertia term is neglected in Eq. (4), and the balance of the gravitational and the buoyant forces are considered.

When $D_1 - d + h_1 < h_0$, Eq. (2) is replaced by

$$\rho_F g h_0 = \frac{1}{2}\rho_F u_p^2 + \rho_F g(D_1 - d + h_1) + \frac{1}{2}\rho_F \mu u_p^2, \tag{8}$$

or

$$u_p = -\sqrt{\frac{2g}{1+\mu}|(D_1 - d + h_1) - h_0|}. \tag{9}$$

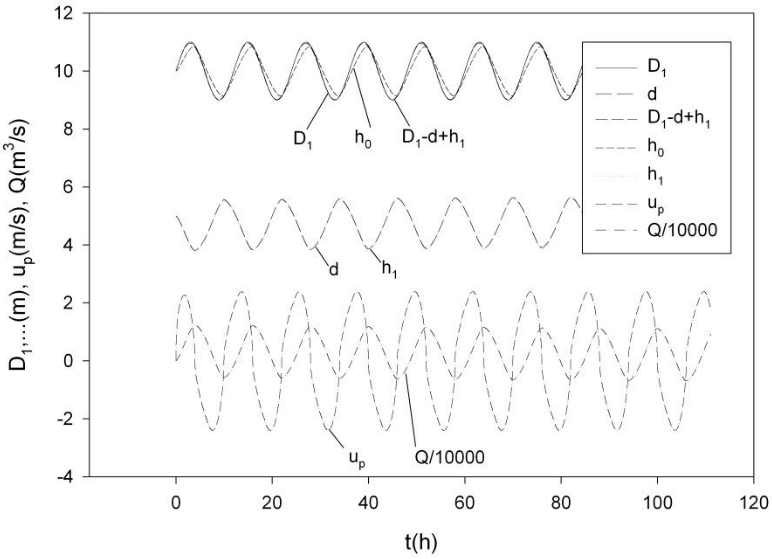
Hence, the same governing equations (4), (5), (6) and (7) apply when $D_1 - d + h_1 < h_0$.

Elminating d from Eqs. (4) and (5) and substituting $u_p = (h_0, h_1, D(t))$ into Eqs. (6) and (7), we obtain ordinary differential equations for h_0 and h_1. h_0 and h_1 are obtained by Runge-Kutta method numerically.

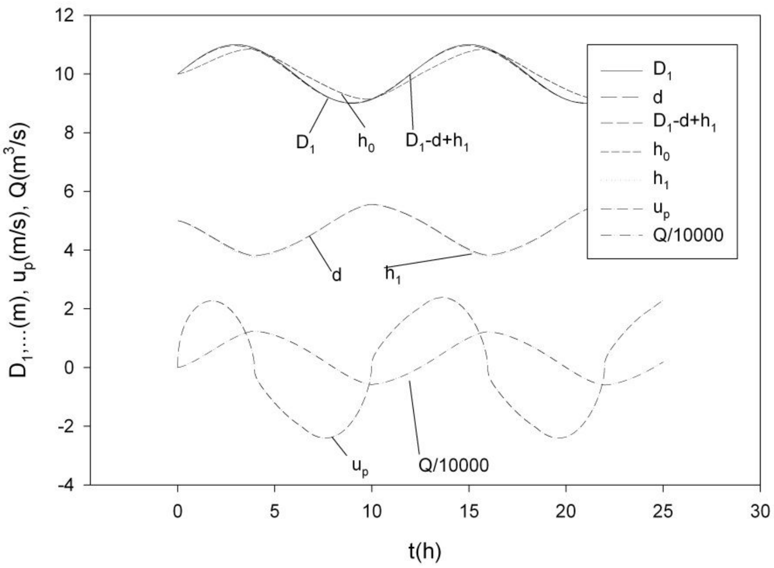
A numerical example is conducted. The parameters used in the calculation are shown in Tab. 1, and the results in Fig. 4a. The details are shown in Fig. 4b. In this example, the mean draft of the float is constant. A little bit smaller change of the water level than that of the sea surface is taking place in Utsuro. As can be seen in Fig. 4b, a small phase delay occurs because of the friction in the flow in the connecting pipe.

Tab.1 Parameters used in a numerical example.

item	value	item	value	item	value
g	$9.8\,m/s^2$	S_0	$10{,}000\,m^2$	h_0	$10\,m$
ρ_F	$1000\,kg/m^3$	S_1	$10{,}000\,m^2$	h_1	$5\,m$
ρ_S	$1040\,kg/m^3$	S_p	$0.5\,m^2$	M_1	$2{,}000{,}000\,kg$
μ	0.2 (-)	D_m	$10\,m$	dt	$1\,s$
α	$0.00001\,m^2$	A	$1\,m$		
D_0	$10\,m$	T	$12\,h$		



(a)



(b)

Fig.4 Motion of water in utsuro and float ($M_1 = 2{,}000{,}000\,kg$)

The other numerical examples are shown in Figs. 5 and 6. M_1 in Figs. 5 and that in Figs. 6 are $100{,}000kg$ and $10{,}000{,}000kg$, respectively. The float continues to float up in Fig. 5 and to sink in Fig. 6.

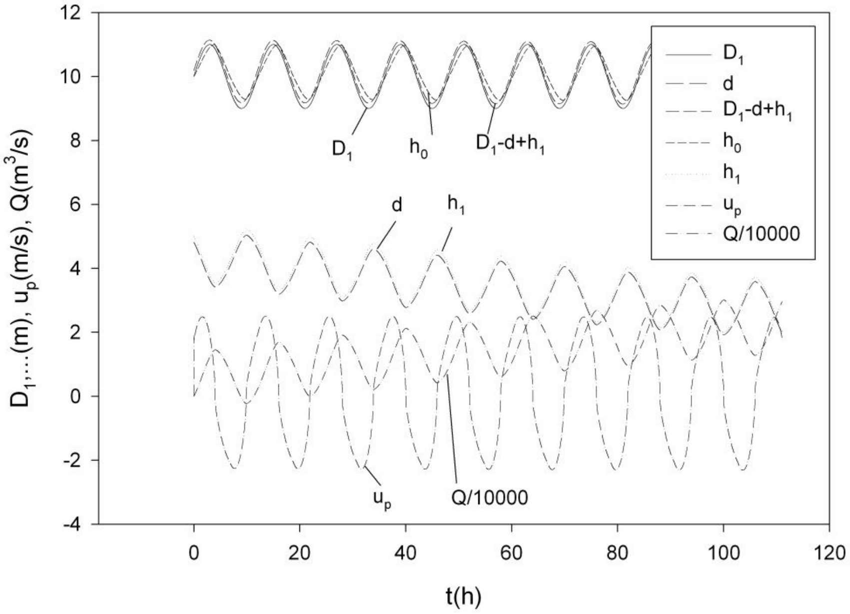


Fig.5 Motion of water in utsuro and float ($M_1 = 100{,}000kg$)

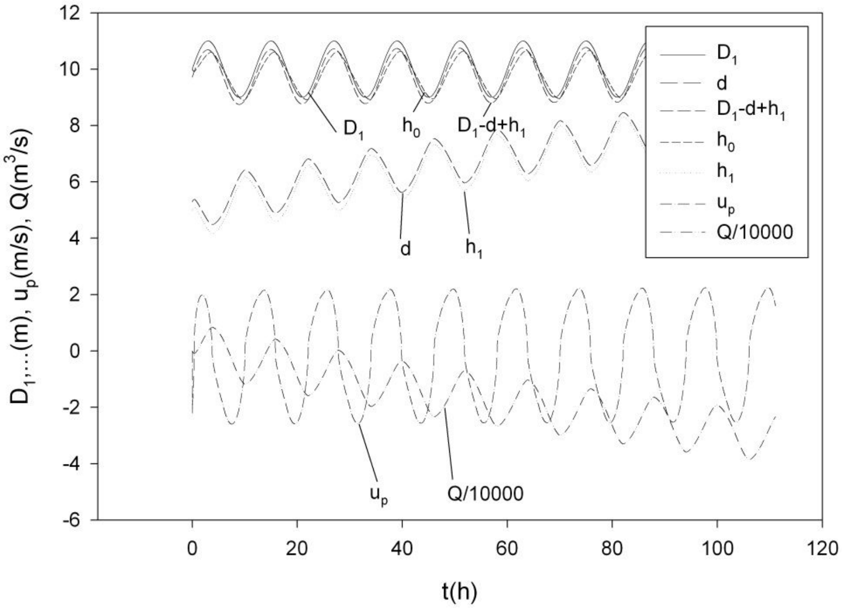


Fig.6 Motion of water in utsuro and float ($M_1 = 5{,}000{,}000kg$)

4. Conclusion

Korea's representative reclamation projects on lake Shiwha and Saemangum located in the western part of Korea have been successfully constructed for decades with much emphasis on protection of environments.

Water purification by passing water through the mount, in which the tidal current is used, can act to tackle with water pollution in case of a salt water lake. What we focus in this paper academically is our effort to reduce pollution of freshwater lake after closing the breakwater completely at the region of large tidal current. We suggest new types of the Utsuro system that includes the reciprocal action of the tidal difference, the change of water level in and out of the Utsuro, the production of bio-films on the rubbles. They result in the purification around the Utsuro. One uses inflatable bag on the seabed within the Utsuro to generate the flow in and out of it. The other uses a float body in the sea side out of breakwater. Hydrodynamic effect causes flow through the pipe connected between inside of the Utsuro and the float. Meanwhile, it could install a filter system in the float instead of the construction of the Utsuro.

The suggested system could be extended in a fresh water lake made at river mouth and used to prevent water pollution after the breakwater installation.

If we replace the fresh water lake with the contaminated water reservoir, the same principle applies to the purification of contaminated water.

A theory was developed for estimating the performance of a system consisting of a utsuro in a fresh water lake and a float at sea, and some numerical calculations were conducted. When constructing the float, appropriate mooring and ballasting device must be developed to prevent the sinking and surfacing of the float.

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