Stockholm Junior Water Prize 2018

Designing rainwater drain structure for pre-treatment of non-point source pollution

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(Do you love water?)

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<Abstract>

In case of the occurrence of flood and inundation, it can lead to direct damages such as physical damage or casualties as well as secondary damage, that is, facility degradation and environmental damage caused by non-point pollutants of run-off. When it comes to the secondary damage, there used to be lack of awareness about environmental problems caused by typhoon and inundation. It wasn't until recently that a number of studies and measures have been discussed slowly.

We began this study aiming to prevent secondary damage from flood and inundation and protect river vegetation and environment, reducing sewage's burden by handling it primarily. For that end, we decided to design drainage channels less affected by non-point pollutants. We chose some ideas from brainstorming and conducted experiments. Then, based on the experiment results, we further developed ideas and came up with final model after going through 4 experiments in total.

We carried out experiments to reduce non-point pollutants in the following sequence: applying Delta submerge principle; using screw structure and absorption method; using Gyre model's centrifugation; using small Vortex structure; and using Venturi model's structural characteristics. Through the four experiments, we aimed to produce an optimal drainage structure by analyzing relations among different variables based on the efficiency analysis by model. Finally, the Venturi channel with bending part of special angle showed the highest efficiency in terms of drainage efficiency and elimination of non-point contaminants.

It is not only more efficient than other structures in the efficiency of drainage and elimination of non-point pollutants, but also it can be applied to various drainage environments such as bridges, slopes, and road surface, etc. The use of this drainage structure in many agencies and locations will be easier to install, manage and maintain, and it will make it more efficient to respond to run-off and environment in the event of inundation, which thereby will be beneficial both in the long and short terms.

<Key words>

- Non-point pollutant
- Swirl
- Sediment
- Venturi tube

1. Introduction

1.1 Background and purpose of study

As No.5 typhoon 'Noru' moved northward to the Korean Peninsula in the summer of 2017, the entire Korean peninsula including Jeju Island was affected by the fifth typhoon. Flood and inundation damage occurs in many ways. Most people, however, focus on visible and material damage only such as destruction and financial damage, and most of the flood countermeasures are also focused on it. However, damage countermeasures currently being studied focus on addressing not only short-term but also long-term damage: that is no other than an environmental problem.

Non-point pollutants are formed with contaminants on the road swept away when river overflows by rainfall. Non-point pollutants are a main culprit of the destruction of modern aquatic vegetation and environment, which is recently studied with increasing awareness of environmental issues. Since researches have not been carried out for very long, it is still an area that needs further exploration and we wanted to solve it by ourselves.

We have devised various types of methods to address non-point pollutants and to prevent flooding by inundations. As a result, four types of solutions were specified in the process of developing and fleshing out ideas, and the verification process of experiments was used to create the most efficient type of drainage structure in terms of non-point pollutant elimination and flooding prevention.

1.2 Theoretical Background

Non-point pollutants are difficult to deal with because of their unknown origin and a combination of various pollutants, which poses a serious threat to the underwater ecosystem. As for the source of point pollution, it is uniform and treatment facilities and countermeasures are already in place based on a number of prior researches. Thus, researchers and the Ministry of Land, Infrastructure, and Transport are pointing out non-point pollutant as the most critical pollutant among water pollution sources [1].

The types of non-point pollutants are as follows:

1) Earth and sand
2) Asphalt and bridge (facility) by-product
3) Exhaust gas deposits (sulfur oxide)
4) Sedimentation in soil (pesticide and fertilizer - phosphoric acid)

In addition, in the process of studying preceding researches, we found a research to replace drainage channel of point drainage type existing in bridges with drainage channel of line drainage type.

A pentagonal drainage structure was adopted to ensure that water can flow out smoothly even when water flow is small in small cities, and drain pipes were connected with inclination of 0.6% to prevent small particles from being deposited to block drain pipes. Also, to prevent the inflow of large deposits, the size of the intake zone was adjusted on the roadway and road surface.

Although this line drainage study was different from our study in its purpose, it was worthwhile to consider rate of inclined structure to move water flow efficiently as well as methods to block deposits [2].

While searching for water purification and sediment treatment methods, we came to learn about CDI technology. CDI stands for 'capacitive deionization', which means electrical adsorption technology. When the electrode is applied with potential, the adsorption reaction that occurs in the mid-layer of the electrode interface can be used to remove any ionic suspension in water. However, considering the availability conditions of the electric absorption technology and the conditions of actual flood, we reached a conclusion that the electric absorption technology was unsuitable. This served as an opportunity to change direction from chemical process to physical process.

We realized that it was more effective to use simpler structural and mechanical methods than chemical and electromagnetic methods and focused on designing methods that used geometric structures [3].

Following consideration of water purification technology, we discovered an ultrasonic shock water purification method by investigating ways to treat sediments. Along with sterilization process through ozone gas, this method applies ultrasonic waves of a certain wavelength range to the drain tube to form a micro structure in which vacuum areas and tight areas are repeated inside the drain pipe, and to clean deposits within drainage pipe through peeling effect by vibration energy. The use of this method to clean drain pipe will allow for the systematic development by increasing treatment efficiency after deposition [4].

Through these processes, we came to be more aware of environmental problems and eventually conducted research to eliminate non-point pollutants and prevent inundation by floods.

2. Materials and Methods

2.1 Production of miniature models

In this research, we conducted experiments to find an effective drainage structure to purify water containing non-point pollutants and to prevent flooding. We made miniature models for the experiments by ourselves. Following are the four types of miniature models.

We designed various structures based on existing theories and background knowledge combined with our ideas to effectively eliminate non-point pollutants defined above from flowing water. We conducted following experiments to compare dry mass of eliminated pollution sources depending on structure and condition. This was to verify designed structures' ability to eliminate pollution source and its efficiency, and to specify how to increase elimination rate in each structure.

(A)

(B)

Figure 1(A) Delta model (outside), (B) (inside)

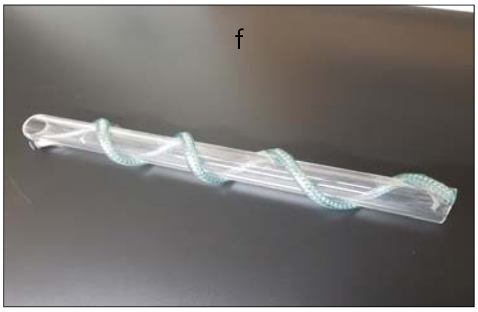


Figure 2 Gyre model

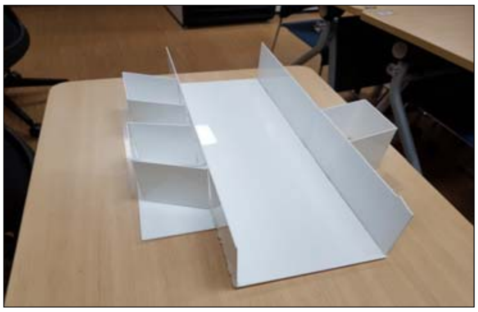


Figure 3 Vortex model

Figure 4 Venturi model

• Comparison of deposition

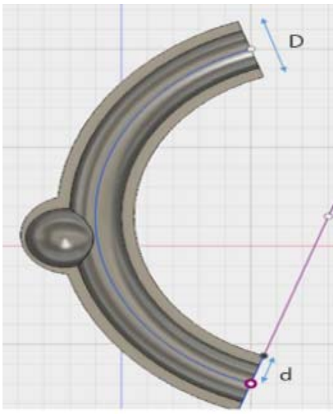
If we disembogue pollution water (muddy water) into miniature models, deposition is formed inside model according to each principle. We analyzed model's ability of separating non-point pollutant through weighing method because amount of sediment is equal to that of non-point pollutant filtered from flowing water.

2.2 Experiment of Delta model

A Delta is a sedimentary topography developed in the mouth of river. It is one of alluvial plains where earth and sand flowing in the river is accumulated in the estuary, and it usually forms a triangle.

Generally, Delta is formed by the change of the force acting on the soil with significant decrease in the flow velocity of flowing water that transports sediment. Therefore, even if the direction of the force changes, soil can be deposited.

(A)



(B)

Figure 5(A) Picture of Delta model,

(B) Working principle of Delta model

When water flow is insufficient, water flows through the large tube with diameter D. If it is sufficient, water flows through the small tube at the top of drainage channel with diameter d, and soil is deposited as shown in Figure 5. That's how we created the delta model.

<Experimental Design>

(1) Experiment preparation material: motor, non-point pollutants (sand, by-products of asphalt and bridges (facility), exhaust gas deposits (sulfur oxides), sediment in soil (pesticide and fertilizer - phosphate acid)), alternative soil, small pump, acrylic tank, hose, acrylic pipe, electronic scale

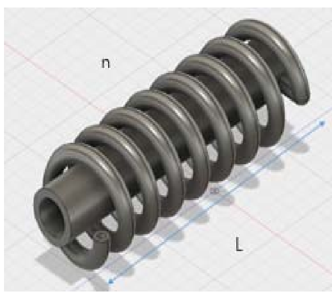
(2) Experiment method and process

- Make drainage circuit in the order of waterworks, pumps, hoses, acrylic pipe and acrylic tank.
- Distinguish the models considering volume ratio of space ($\frac{d^3}{D^3} \times 100(\%)$), the radius of curvature and diameter of hose (d).
- Do the test by the various models.
- Collect the precipitate and measure the amount. Repeat this process three times to calculate the average.
- Analyze model's ability based on data of dry masses.

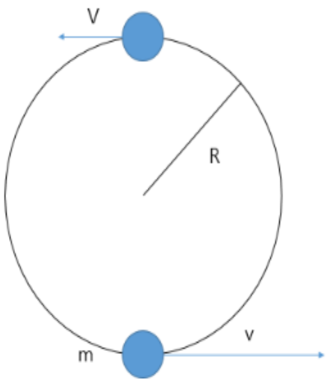
We tried to find relationship between the diameter (D) of hose and deposition amount, and radius of curvature and deposition at different volume ratio of space ($\frac{d^3}{D^3} \times 100(\%)$).

2.3 Experiment of Gyre model

We made a Gyre model using centrifugation because of the limitation of the existing adsorption equation method.



(A)



(B)

Figure 6(A) Configuration of Gyre model, (B) Motion in a Gyre

When insufficient amount of water flows in the pipe, the water flows mainly through the pipe whose diameter is D. If amount of water is enough, water flows through small hose whose diameter is d, where soil is deposited by centrifugation.

Doing the test, we tried to confirm if this model could actually deposit non-point pollutants.

<Theoretical verification process>

We set as follows: R is the diameter of the circular tube formed by the large tube; m is the mass of the non-point pollutant; and v is the velocity at the lower part of gyre. Also, let's assume that only gravity acts on non-point contamination sources (discarded friction and resistance). If the non-point pollution does not rotate completely, the influence of gravity becomes more conspicuous than the centrifugal force when reaching the upper part. Under the assumption that it reaches the upper portion of the circle when the velocity of the contamination source is V, the following relations were obtained.

$$mg(2R) = \frac{1}{2}m(v^2 - V^2)$$

$$\frac{mV^2}{R} \leq mg$$

From two simultaneous equations,

$$2mgR = \frac{1}{2}m(v^2 - V^2) \geq \frac{1}{2}mv^2 - \frac{1}{2}mgR$$

$$v^2 \leq 5gR.$$

We can correct the situation. If we make a steep slope, it can increase the speed of flowing water.

<Experimental Design>

(1) Experiment material: motor, non-point pollutants (sand, by-products of asphalt and bridges (facility), exhaust gas deposits (sulfur oxides), sediment in soil (pesticide and fertilizer - phosphate storage)), alternative soil, small pump, acrylic tank, hose, acrylic pipe, electronic scale

(2) Experiments method and process

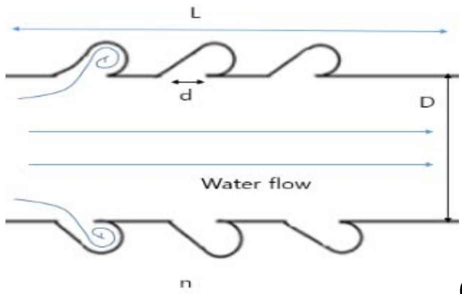
- Make drainage circuit in the order of waterworks, pumps, hoses, acrylic pipe and acrylic tank.
- Distinguish the models by the number of coiling per unit length (n/L)
- Do the test by the various models.

- Collect the precipitate and measure the amount. Repeat this process three times to calculate the average.
- Analyze model's ability based on the data of dry masses.

We tried to find relationship between the number of coiling per unit length (n/L) and deposition in the gyre model.

2.4 Experiment of Vortex model

The change in space and path through which fluid passes in fluid dynamics forms instantaneous velocity difference of fluid based on Bernoulli's theorem and continuous equation. A vortex is formed at the speed conversion point, but when a vortex is formed in a limited space, a substance whose density is higher than that of water sinks and accelerates. Then, one can see a phenomenon where deposits gather at the lower end of the vortex flow. The vortex flow formed in this way reduces the amount of major mechanical energy that passes through drainage channel, decreasing the flow rate and depositing sand and the pollution source flown into the flowing water due to the influence of the eddy current.



(A)

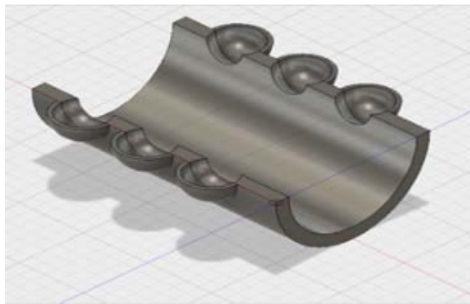

(B)

Figure 7(A) Vortex structure, (B) Cross section of vortex model

<Experimental Design>

(1) Experiment preparation material: motor, non-point pollutants (sand, by-products of asphalt and bridges (facility), exhaust gas deposits (sulfur oxides), sediment in soil (pesticide and fertilizer - phosphate storage)) alternative soil, small pump, acrylic tank, hose, acrylic pipe, electronic scale

(2) Experiment method and process

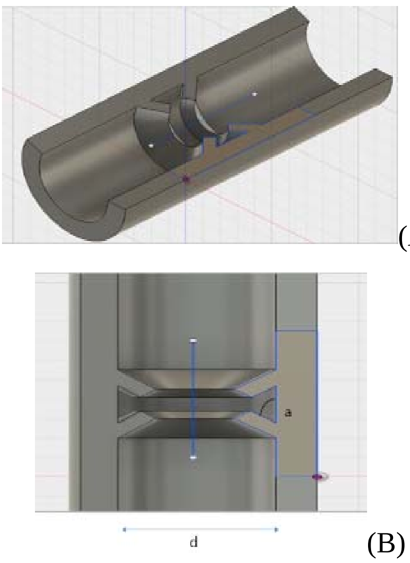
- Make drainage circuit in the order of waterworks, pumps, hoses, acrylic pipe and acrylic tank.
- Separate the models considering ratio of the space ($\frac{d}{D}\times 100(\%)$) and the number of coiling per unit length (n/L).
- Do the test by the various models.

- Collect the precipitate and measure the amount. Repeat this process three times to calculate the average.
- Analyze model's ability based on the data of dry masses.

We tried to find relationship between ratio of the space ($\frac{d}{D}\times 100(\%)$) and deposition, and the number of coiling per unit length (n/L) and deposition in the vortex model.

2.5 Experiment of Venturi model

The Venturi tube is characterized by a phenomenon in which a hydraulic pressure difference occurs in the inlet and outlet and flow velocity increases where, in the side, water flow is stagnated and the flow velocity decreases.



(A)

(B)

Figure 8(A) Cross section of Venturi model (side), (B) (front)

In the situation where the flow velocity rapidly increases, a folded portion (bending) was installed on the vane of the Venturi tube to form a precipitate on the side surface by the generation of a vortex in the folded portion to remove non-point pollution. Since the degree and form of eddy current differ depending on the angle, length, shape of bending, we tried to find an effective structure to eliminate non-point pollutants. For this end, we designed several models and conducted experiment as follows.

And we judged that the Venturi model of cylinder tube would be too difficult to realize, so we made miniature model by having Venturi structure within rectangular tube.

<Experimental Design>

(1) Experiment preparation material: motor, non-point pollutants (sand, by-products of asphalt and bridges (facility), exhaust gas deposits (sulfur oxides), sediment in soil (pesticide and fertilizer - phosphate storage)), alternative soil, small pump, acrylic tank, hose, acrylic pipe, electronic scale

(2) Experiments method and process
- Make drainage circuit in the order of waterworks, pumps, hoses, acrylic pipe and acrylic tank.
- Do the test by the various models.
- Collect the precipitate and measure the amount. Repeat this process three times to calculate the

average. And analyze model's ability based on data of dry masses.

We tried to find relationship between diameter and deposition, and ratio of angle and deposition in the Venturi model.

3. Results

3.1 Results of Delta model

When the direction of force changes in the delta, a momentary reduction in flow velocity occurs. By measuring the diameter of the hose, the ratio of the volume of the space to the cross-section of the hose, and the degree of change of direction of the hose, the correlation between them can be identified and a model can be made using the principles of this delta. The following data are the measurements of these variables. However, we prepared the deposition in g, diameter of the hose in cm, volume ratio in %, and degree of change in direction in °.

① Delta model experiment - data considering diameter of hose (D)

Generally, the amount of sediment showed tendency to increase in proportion to the diameter of the hose. However, in some parts, the amount of sediment was measured regardless of the diameter of the hose.

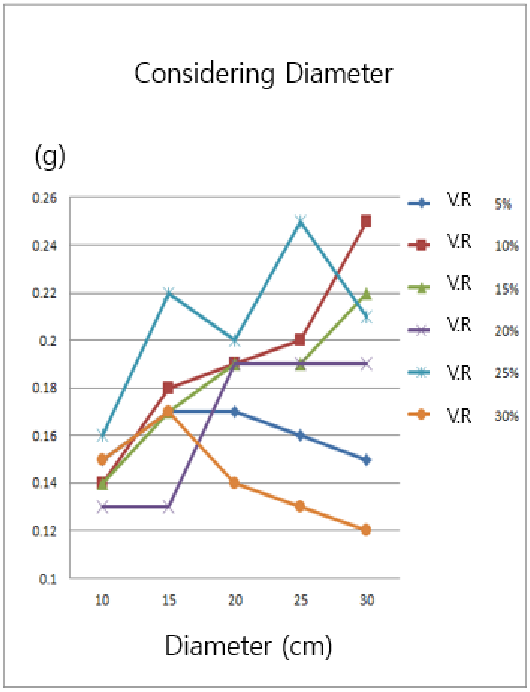


Figure 9 Delta model data: Diameter

② Delta model experiment - data considering radius of curvature

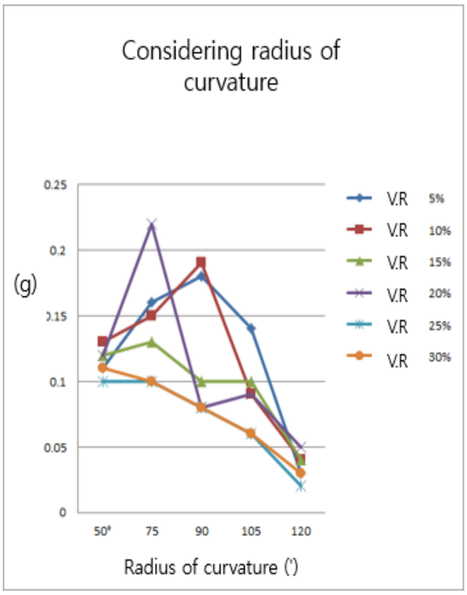


Figure 10 Delta model data: Radius of curvature

As for hoses within less than 10 % volume ratio, the volume of deposition continued to increase up to 90 degrees and then decreased. As for hoses with 15 % or higher volume ratio, the volume of deposition tended to decrease gradually as the angle increases.

3.2 Results of Gyre Model

In the form of drainage of a gyre structure, water flows through thick tubes surrounding narrow tube, rotating non-point pollutants and settling them at the bottom by centrifugal force. Therefore, the amount of deposition will be affected by the number of turns and the ratio of the diameter between the two hoses. The following are the results of test per the number of turns. However, the deposition amount shall be expressed in g.

<Gyre model experiment – Number of turns per unit length (n/L), L = 50cm>

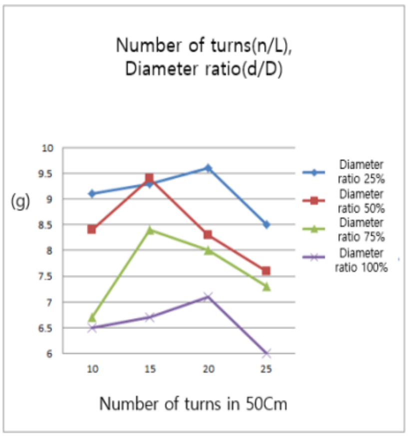


Figure 11 Gyre model data

First, the lower the diameter ratio (d/D) was, the higher the deposition was. As for the amount of deposition according to number of rotation, rotations over a certain limit resulted in reduced deposition efficiency, which varied depending on the ratio of diameters.

When water rotates several circles, the number of fluid particles which have enough potential energy needed for rotation decreases. Then, they fail to rotate screw completely.

3.3 Results of Vortex Model

This is a structure to settle sands or pollutants passing through discharge channel using vortex. We secured a space to form a vortex on the sidewall in this experiment where the amount of deposition changed depending on the ratio of the area of the vortex formation space to the width of the channel, the eccentricity of the vortex formation space, and the number of vortex formation space. The following are the results of this experiment. We expressed the deposition amount in g, and the area ratio of hose width in %.

<Vortex model experiment – number of spaces per unit length (n/L), area ratio of space to hose width (d/D), L = 50cm>

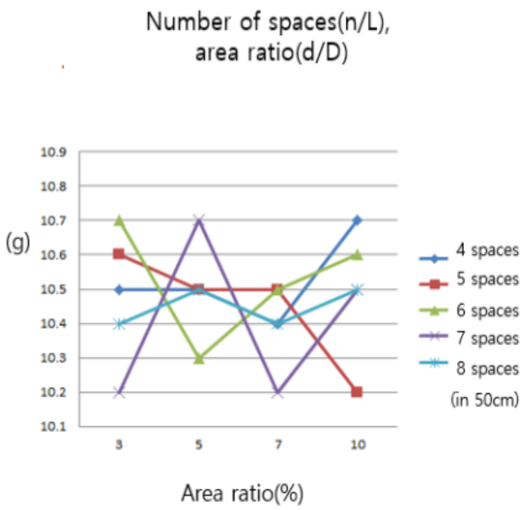


Figure 12 Vortex model data

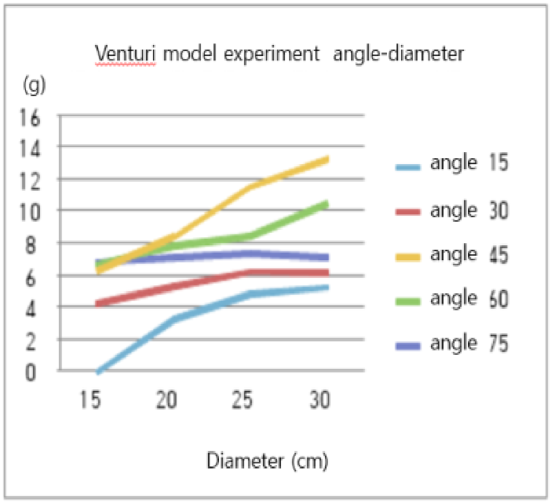


Figure 13 Venturi model data

The amount of sediment fluctuated around approximately 10g, regardless of the area ratio of space or number of spaces.

3.4 Results of Venturi Model

The non-point pollution elimination structure which applies the structural characteristics of a Venturi tube installs bending parts in the wings of a venture. This creates a vortex of sediment when the water speed rapidly increases to eliminate non-point pollutants. Thus, the efficiency will vary according to the angle, length, and shape of the bending.

The following are the results of a model-by-model experiment. We expressed deposition volume in g, the diameter of hoses in cm, and bending angle (°).

Overall, as the diameter of the hose increased, the amount of deposition increased. The maximum deposition was found at 45 degrees of bending angle. This is assumed to be because vortex formation was the best at this angle.

4. Discussion

4.1 Performance of Delta model

A) Hose turning degree (T.D.)

According to experiment result analysis, there is proportional relation between T.D. and amount of deposition only when T.D. is lower than 75°. This is because water sweeps away deposition if T.D. is higher than a specific value. By using result analysis 3-3, we can infer that the value is 90°. Additionally, 75° T.D. model had the heaviest soil.

B) Diameter

When hose's diameter was shorter than 20cm, amount of sediment increased as diameter became longer. We assumed this is because the area of deposition storage space increased in proportion to volume ratio, making it easier for water to flow again.

C) Poor sediment amount

The average amount of sediment measured was approximately 0.2g. This is absolutely insufficient compared to soil amount in muddy water we made. This is because of delta system's structure feature mentioned in (A), (B).

<Countermeasures>

When water flows through this hose, water concentrates on edges, so sedimentation effect decreases. If we install some motors in the middle of hose to circulate water, soil will be deposited more.

<Possibility practical use of this model>

There is a practical feasibility. Factors which are needed to be considered have regular relations, so we can make efficiency higher with more study. Also, there are sufficient conditions with maximum sediments, so we can generate a hose mixing these.

However, there is not appropriate ways to treat deposited pollutants. There are some ways such as injecting water again or making detachable system to wash depositions. However, these methods cannot be used during rainy season. We believe this system has feasibility if we find an appropriate way to treat these pollutants.

4.2 Performance of Gyre model

A) Number of rotations (N.R.)

As N.R. increases, fluid revolves more, so it is more likely to be deposited. In case that N.R. is higher than 25, sedimentation efficiency decreases. When water rotates several circles, the number of fluid particles which have enough potential energy needed for rotation decreases. Then, they fail to rotate screw completely, and leave pollutants not only on the bottom part but also on the upper and side parts to drop sedimentation efficiency. The phenomenon in which hose whose N.R. is 25 and volume rate is 100% cannot rotate completely proves it.

B) Diameter ratio (D.R.)

As D.R. increases, amount of sediment increases with the amount of fluid flowing in going up. However, since fluid particles need to travel wider and longer distances, the number of fluid particles that pass through all tubes completely decreases, leading to less amount of sediment. Comparing the two factors, the result came out because decrease factor is superior to increase factor.

<Countermeasures>

To get more efficiency, we can make a groove in a hose to have sediments gather together. Also, in order to supplement decreasing factor: fluid particles which can't revolve completely, we can narrow down screw's upper distance to reduce the number of fluid particles that cannot revolve completely. This is the first time when experimental variables have regular relations among many models mentioned above, so it will be able to supple shortcomings by using these relations.

<Possibility of practical use of this model>

We think the possibility is low. According to the experiment result, pollutants of 6.0g - 9.7g were deposited. Its efficiency is higher compared with delta model. However, the amount is not enough. If we connect many systems consecutively, it will be possible to filter most of pollutants. There is problem, too.

It is actually inefficient, and there was a phenomenon where sediments passed through hose appeared again. The practical possibility is low as it is difficult to guarantee continuous settlement of pollutants.

4.3 Performance of Vortex model

A) Number of space (N.S.)

Although N.S. increased, total mass of sedimentation was similar. This is because each space had impact on flow.

B) Space area ratio to hose width (A.W.)

Although A.W. increased, total mass of sedimentation was similar. We assume that this is because the amount of fluid inflow increased with the increase of A.W., but force needed to be deposited increased as well.

<Countermeasures>

According to result analysis, the most amount of sediment was measured when volume ratio was 15% with 75° degree of turning of the hose and diameter of hose being 20cm. If we turn direction several times maintaining this condition, efficiency will increase slightly.

<Possibility of practical use of this model>

It was hard to find relations among variables through this experiment. We concluded that we would be able to develop the model further if we get more information about relations through repeated experiments, but it seems difficult to find relations. However, sedimentation efficiency is far higher than that of former two models.

4.4 Performance of Venturi

A) Bending part (B.P.) length, angle

As B.P. or angle increases, amount of sedimentation becomes higher. However, if one of 2 factors is higher than a certain limit, result decreases. This is related to the principle of swirl formation. In Venturi model, swirl appears by flowing water's velocity change in the bending part. Therefore, bending part's vertical direction length should not obstruct flow when swirl is generated. In other words, if B.P. or angle is too big, it disturbs flow of water directly and blocks swirl formation.

<Countermeasures>

Through various experiments, we can get the best efficient ratio between hose's length, B.P, angle and sedimentation. Using the ratio, we would be able to make the most proper drain system.

<Possibility of practical use of this model>

Possibility is very high. Mass of sedimentation is heavier than that of other 3 models, and the model is the simplest to generate. Also, we can create appropriate model according to various topography and structure using relations between B.P. and angle tendency. We don't have to be concerned about deposits against fluid's direction, resulting in sedimentation of pollutants for a long time. We can treat them by making a groove for inhalation as pollutants can be stored for a long time. This can also address the problem which gyre model could not resolve.

4.5 Overall discussion

According to the experiment result of a total of four drain systems, we confirmed that all systems submerged soil which replaced non-point pollutants. Even in one system, amount of soil was different depending on conditions. In some situations, two conditions increased proportionally whereas there were also conditions with irregular relations. Considering difference between these conditions, the most efficient systems were vortex and Venturi.

The maximum value was 10.7g in vortex model and 13.0g in Venturi model. One of common features of these models is that they submerge soil by producing swirl. Through this experiment, it was proven how much swirl can increase drainage efficiency.

When we produced the model, we did it manually by ourselves. Making Venturi model was easier than other models. Vortex needed additional processes after Venturi. It was hard to find hoses with different diameters to make the other 2 structures. We do not know how much difference there will be in case of mass-production, but the difference will be maximized.

Venturi model was far more outstanding than others in terms of sedimentation efficiency and convenience of model production.

5. Conclusion

As a result of designing drainage channel of treating non-point pollutants primarily, we finally came up with four models: Delta model, Gyre model, Vortex model, and Venturi model. As a result of analyzing model efficiency based on experiment result, Vortex model and Venturi model which form swirl were found better than Gyre model and Delta model in terms of efficiency. Also, Venturi model was the easiest to make based on our experience, which was followed by Gyre and Delta model. In term of making the model and removing pollutants, Venturi was a perfect model.

Based on the results of this study, non-point pollutants can be eliminated without the use of resources including electricity.

Moreover, thanks to the benefits of removing contaminants through physical structures, the system can be used effectively for various drainage environments, such as bridges, slopes, and underground roads. A gradual water purification method in a tube through drainage rather than elimination of large amounts of pollutants at once can reduce the investment time involved in improving flood damage.

On the other hand, we cannot deny the fact that there are limitations. This model cannot remove the contaminants that need chemical processes and also it takes time and money to remove the contaminants deposited in the tubes. Although it is not clear yet how to improve, it will be possible to assemble drainage channels to increase efficiency of cleaning process or to remove suspended solids through chemical coating processes inside the drain pipes. If further experimentation is conducted and feedback is used to reinforce existing pollutant removal methods and to complement such complex problems, installation process, manufacturing and dissemination may become easy and it will be used well in all sorts of terrains.

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