Which Shape can Lessen the Force of Tsunami?

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Abstract

Our goal is to find the best structure for attenuating a tsunami. We concluded that the double cylinder type structure has least effect on the ecosystem and good attenuation efficiency. In addition, when experiments were carried out by changing the size of the structure, we found that the double cylinder type structure had the same or a higher attenuating efficiency than the others even when the structure was made small.

1. Introduction

On March 11th, 2011, the Great East Japan Earthquake occurred and some tsunamis hit the Tohoku district. It caused serious damages; 19,630 people were killed, and 2,569 people are still missing even now. Out of these who died in the disaster, 9/10 drowned in the tsunami. Moreover, researchers say there is a 70~80% probability the Nankai Megathrust Earthquake will occur in the next 30 years. If it does, the tsunamis which caused by this earthquake will also be ruinous to Japan. The construction of embankments is one of method to reduce tsunami damage, but we focused on another method: to put a sub-marine structure on the seabed. Several studies have reported that the method is effective to reduce the damage of a tsunami. However, we feared that the structure would block normal current and have an impact on the seafloor ecosystems. Therefore, the purpose of our research was to propose a new and ideal sub-marine structure which satisfies two requirements: should not prevent normal current, and should attenuate the tsunami damage efficiently.

2. Research Technique

2-1. Tsunami Model

We studied what using the experimental equipment used in last year's AI project (Fig. 1).

Figure 1: the Tsunami Model We Used

When doing an experiment, the system generates tsunami-like waves by pulling strings connected to a board (the submarine plate) on the bottom of the device.

2-2. Experimental Procedure

i) **Generate a tsunami-like wave** by installing a structure on the bottom of the experimental equipment

ii) **Take a movie** of the wave

iii) **Find the wave height** from the video. The reference plane of the wave height here is the water surface in still water, and the difference between the highest part of the tsunami and the reference plane is obtained when the wave height is measured.

iv) **Analyze the changes** in wave height before and after adding the structure using the T test to verify whether they are significant (significance level of 5%)

v) If the null hypothesis is rejected in iv), **calculate the attenuation rate** of the tsunami from the change in wave height based on Expression.1, and the average value is obtained by subtracting the maximum and minimum values.

2-3. Structure Used in the Experiment

The experiment was carried out using the ABS (acrylonitrile-butadiene-styrene) resin structure output by the 3D printer. The structure was fixed to the bottom surface of the experimental equipment using gummed tape and thin wire because it floats in water. The surface area of the side facing the tsunami was the same on each structure.

2-4. Definition of tsunami attenuation rate

It is very difficult to continue the experiment under the same conditions using manual plate lifting techniques. Therefore, it was assumed that the tsunami was attenuated by the structure at a certain rate, and the rate was defined as the attenuation rate as (Equation.1).

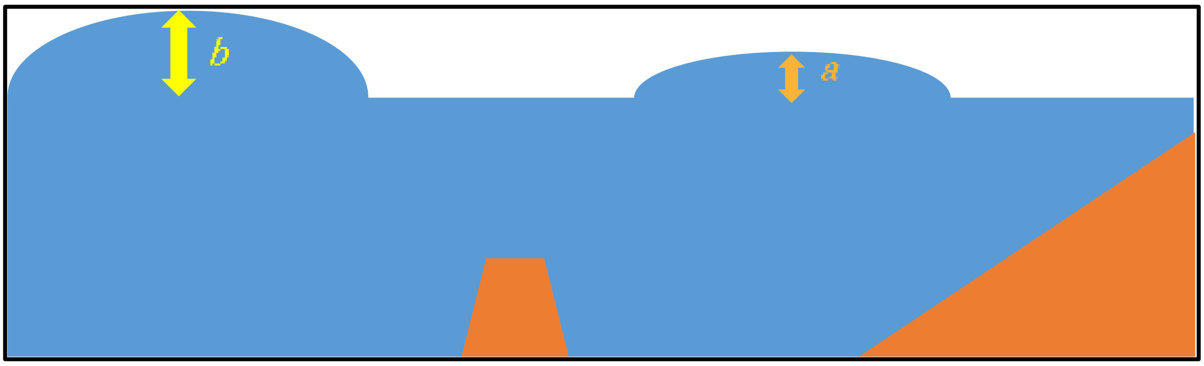
Equation 1: Attenuation Rate

$$R = \frac{b-a}{b} \times 100$$

* $R =$ (attenuation rate)

$b =$ (the tsunami height before the structure is used)

$a =$ (the tsunami height after the structure is used)



3. Hypothesis

(Hypothesis.1) Attenuation rate of tsunami changes by the structure of the structure installed on the seabed

(Hypothesis.2) Attenuation rate is larger for the structure which generates more vortices on the seabed.

4. What is known from previous research

A) When the tsunami passes over the structure, the direction of the seabed flow is opposite to the direction of the tsunami.

B) It is possible to reduce tsunami energy by installing a structure on the seabed.

C) The speed of the tsunami does not change before and after passing through the structure.

D) A Vortex, which helps attenuation of the tsunami, is generated around the structure at the moment when the tsunami passes through the structure.

5. Experiment.1) Structure and Attenuation Rate

5-1. Purpose

Investigate the degree of tsunami attenuation caused by the structure and find an appropriate shape.

5-2. Used Structures

The structures shown in Table 1 were used. The reasons for the election are as follows.

I. The shape should be as simple as possible.
II. The structure should be able to generate many vortices around a structure when the tsunami going through.
III. The shape should not prevent the normal current.

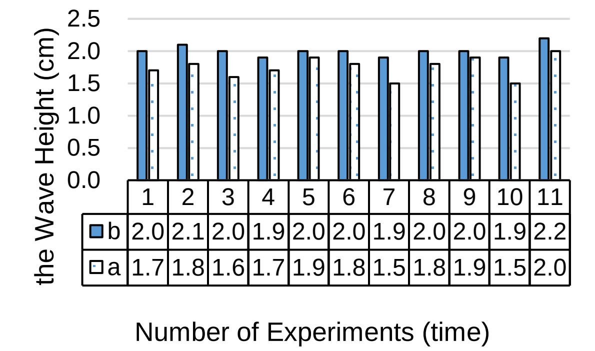
Table 1: Used Structure

	 Cube	 Pyramid	 Double Cylinder
Reason I	✓	✓	✓
Reason II			✓
Reason III			✓

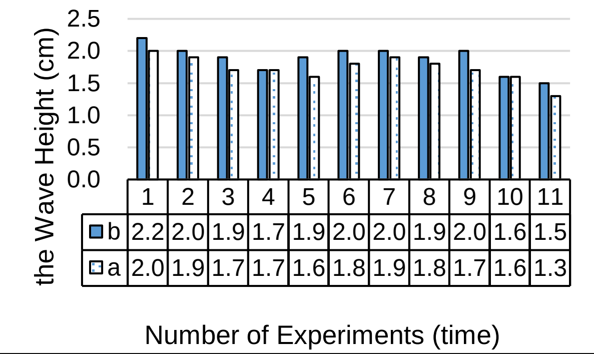
5-3. Result

The results are shown in graph.1 ~ 3 below.

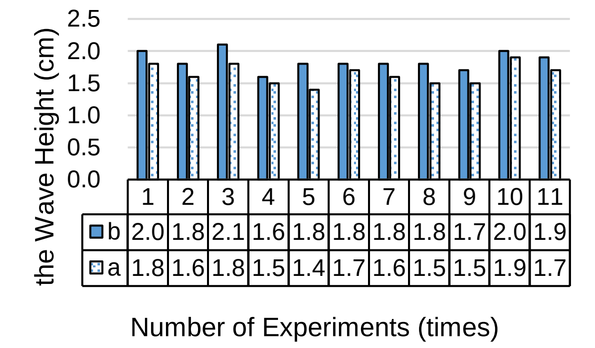
(Graph.1) Cube



(Graph.2) Pyramid



(Graph.3) Double Cylinder



In the cube structure, tsunami attenuation was observed in all experiments, and the average attenuation rate was $\overline{R}$ = 12.8%.

In the pyramid structure, except 4^{th} and 10^{th}, tsunami was reduced in all experiments, and $\overline{R}$ = 8.13%.

In the double cylinder structure, attenuation was observed in all experiments, and $\overline{R}$ = 10.8%.

* In the graph, "b" equals the tsunami height before passing through the structure, and "a" equals the tsunami height after passing through the structure.

Table 2: the Average Attenuation Rate and Standard Deviation in Each Structure

	Cube	Pyramid	Double Cylinder
Average Attenuation Rate (%)	12.8	8.13	10.8
Standard Deviation	5.7	5.3	4.8

5-4. Consideration

From the experiment, it is considered that the cube-shaped structure attenuated the tsunami most efficiently. However, we focused on double cylinder structures. The double cylinder structure has a hole inside to allow waves to pass through. The cube shaped structure's attenuation rate was 2% higher than that of a double cylinder. In a 10 m wave, this would be equal to a 20cm difference in height. Therefore, it was considered that it could be prevented by the height of the embankment. The standard deviation of the double cylinder structure is the smallest among the three structures, and the error associated with the experiment is the smallest. In other words, the double cylinder structure is considered to have a shape capable of surely attenuating tsunami compared with the cube structure and the pyramid type structure.

Here, it is necessary to examine why the double cylinder structure was able to attenuate the tsunami as much as the cube. Therefore, we considered the following three causes. First, the flow inside the double cylinder affected the tsunami attenuation, second, there were many vortices outside the double cylinder, and third, the double cylinder structure, which connected two cylinders, affected the tsunami attenuation. To verify these causes, later experiment.2) and 3) were performed.

6. Experiment.2) Flow Inside the Structure

6-1. Purpose

Examine the flow inside the double cylinder structure.

6-2. Experimental Procedure

A polyethylene colored tape is cut into small pieces and inserted into the structure and generate a tsunami, thereby indirectly observing the water flow inside the structure at the moment the tsunami passes through the structure.

6-3. Result

Color tape did not come out of the structure. However, during laminar flow, which is different from turbulent flow, which is the internal structure of tsunami, was created in the structure, color tape came out from the structure.

6-4. Consideration

It can be said that the flow was not confirmed in the structure when the turbulent flow was generated. However, since the flow was confirmed in the laminar flow, it is considered that the double cylinder structure is a structure which prevents the turbulent flow not the laminar flow. Through the experiment, it can be said that the double cylinder structure is a desirable structure from the viewpoint of the effect on the seabed ecosystem and the efficiency attenuating of tsunami. However, there is a problem. The structure would be too large for the depth of water. As a solution to this problem, we reduced the size of the double cylinder and conducted experiment.4).

7. Experiment.3) the Effects of Structure Connections

7-1. Purpose

Investigate the effect of connecting two structures in parallel on the attenuation of tsunami.

7-2. Used Structures and Conditions

Two cubes of the same size were arranged to connect parallel to one another. The distance between the two cubes was 1.0 cm. (Fig.3)

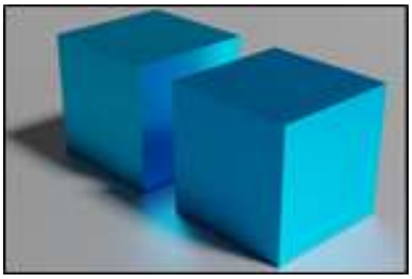
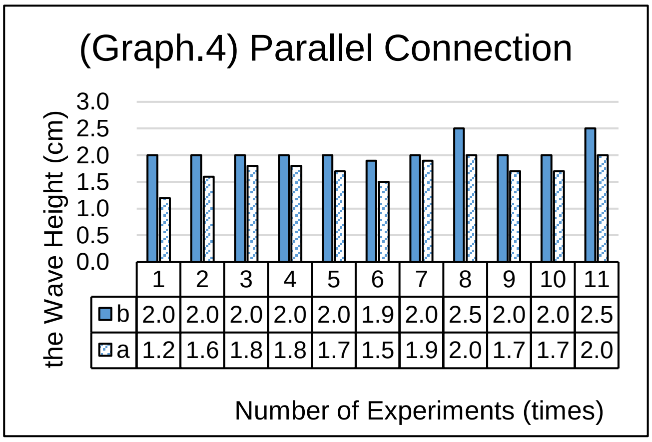


Figure 2: Parallel Connection

7-3. Result

The results are shown in graph.4 below.



* In the graph, “b” equals the tsunami height before passing through the structure, and “a” equals the tsunami height after passing through the structure.

Table.3 shows a comparison of the average attenuation rate between the two situations, two cube structures and one cube structure.

Table 3: Comparison of the Average Attenuation Rate (the Number of the Structures)

	One Cube Structure	Two Cube Structures
Average Attenuation Rate (%)	12.8	16.2
Standard Deviation	5.7	8.7

7-4. Consideration

The experimental results show that the attenuation rate is larger when two structures are connected parallel to one another than when only one structure is used.

8. Experiment.4) Smaller Double Cylinder

8-1. Purpose

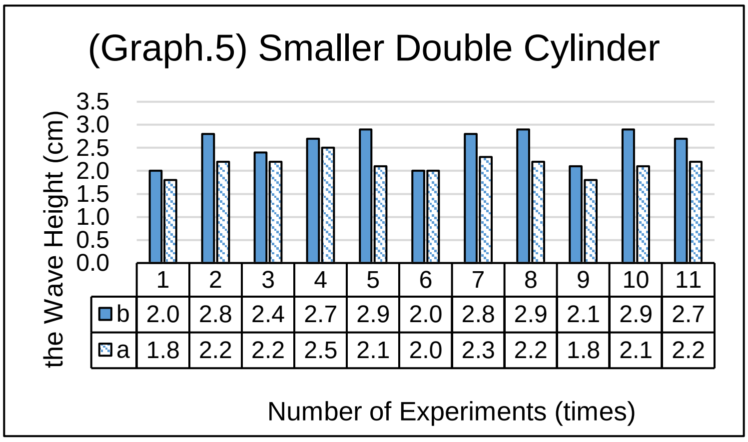
Examine the attenuation rate when the size of the structure is reduced.

8-2. Used Structure

A small double cylinder. The similarity ratio is 1: 2 compared to the normal double cylinder.

8-3. Result

The results are shown in graph.5 below.



* In the graph, "b" equals the tsunami height before passing through the structure, and "a" equals the tsunami height after passing through the structure.

Table.4 shows a comparison of the average attenuation rate between the normal double cylinder and the smaller double cylinder.

Table 4: Comparison of the Average Attenuation Rate (the Size of the Structure)

	Normal Double Cylinder	Smaller Double Cylinder
Average Attenuation Rate (%)	10.8	16.6
Standard Deviation	5.7	8.5

8-4. Consideration

From the experiment, it can be said that a small double cylinder attenuates tsunami more efficiently. Here, the reason why the value of the attenuating ratio is larger for the small double cylinder is discussed. We considered the following reasons. First, the use of small structures increased the surface area or volume that affected sea floor flow, and second, the distance between vortices in small structures increased and the effect of vortices increased.

9. Conclusions and Future Challenges

From the above experiments, even if the water flow outside the structure has not yet been investigated, it can be said that the double cylinder structure is the most suitable for installing on the seabed, from the two viewpoints of attenuating the tsunami and suppressing the effect on the undersea ecosystem. The reason for this is considered to be that the double-cylinder type structure has a structure to block the turbulent flow. Experiments.3) and 4) also show that the structure has a tsunami attenuating effect even when the structure is made smaller. Therefore, it is considered that installing a double cylinder structure on the seabed can effectively attenuate tsunami. But there are challenges. At the moment, the structure is half the depth of the water, and assuming that it is actually installed, the size of the structure would be about 50 m, which is too big. It is also necessary to determine the ratio of the sizes of the two cylinders of the double cylinder, which is most effective in attenuating the tsunami. In addition, for Experiment.3), the distance between structures should be further investigated. Therefore, when considering practical application, it is necessary to investigate what kind of interaction will occur when two or more structures are installed parallel to one another. By installing structures at optimal distances, it can be said that tsunami can be prevented to some extent with the help of these structures and therefore saving many lives.

10. Acknowledgements

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11. References

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12. Key Words

Tsunami, Structure, Attenuation