Proceedings of the 7th International Conference on Asian and Pacific Coasts
(APAC 2013) Bali, Indonesia, September 24-26, 2013

WAVE ENERGY SYSTEM USING PIEZOELECTRIC PANEL

C. Si-bum[1], K. Kyu-han[2], H. Sung-jin[3] and H. Seok-inn[4]

ABSTRACT: In this research, we research the characteristics of a new type of wave-power generation system that deducts ocean wave energy to the front part by installing a piezo-electric element on the outside of the existing harbor structure. The wave-power generation system proposed in this research might be applied to a variety of marine structure, which makes it possible to add wave-power generation capacity to the original structural function. Furthermore, it cost relatively less to build multiple generators, which makes its wave-power generation for a bigger launch. Moreover, it might be developed in link with a tourism complex by adopting the wave-power generation system. Accordingly, we analyze the usability of the existing marine structure and characteristics and current research trend in the ocean wave energy retrieval of the wave-power generation system. In addition, in order to review hydrographic characteristics of the proposed system, seen from the result of carrying out 2-D cross-section hydrographic model test, it is confirmed that the maximum wave pressure and voltage increase when in the cases of higher wave and longer period. The result from hydrographic model test indicates that wave-power generation system using piezoelectric element has different generation volume depending upon crushing wave height rather than incidence cycle. It also indicates that the generation volume increase in positive proportion to the size of ocean wave energy.

Keywords: Wave energy, piezoelectric, wave-power generation system

INTRODUCTION

After the Fukushima nuclear disaster in 2011, radioactive substances have been spreading into the atmosphere and the ocean, causing international concerns about radioactivity. This incident aroused the need for the development of new and renewable energies using nature.

Recently, global interests in the rising oil prices due to the depletion of fossil fuels and the environmental problems are increasing. In response to these problems, research in the new and renewable energies such as solar power is being actively conducted all over the world. Among such energies, the potential of marine energy is highly regarded.

Occupying 71% of the global surface has infinite possibilities to supplement insufficient resources of the earth. The ocean energies in particular is receiving attention as one area of the new and renewable energies for supply of electric power resources in the future. South Korea has high potential for the development of ocean energies because the land is surrounded by water on three sides even though the land size is small. Among them, wave power generation using the forces of waves is being recognized as a possible type of power energy that can be utilized in every coast of South Korea.

The energy conversion methods of wave power energy are classified into oscillating bodies, run up, and oscillating water column depending on the method of converting kinetic energy into mechanical energy.

Because wave power generation equipment directly uses the wave energy, the power generation efficiency depends on the size of wave energy.

Waver power generation in South Korea has high energy recovery costs compared to the conventional fossil fuels and the actual electricity production efficiency is low compared to the generation quantity. The sites for wave power plants are also limited to specific areas depending on the wave power generation method and wave energy size.

Moreover, due to the nature of wave power generators that must endure waves, their durability is also critical. As they are mostly installed in deep seas, their operating costs are high.

For these reasons, conventional wave power generators were limited in areas and could not stably generate electricity, resulting in low electricity production efficiency, economic efficiency and practicality.

In this study, a new type of wave power generation system was designed which deducts ocean wave energy

[1] Disaster Prevention Research Department, National Disaster Management Institute, 136 Mapo-daero, Mapo-gu, Seoul, 121-719, KOREA
[2] Department of Civil Engineering, Kwandong University, 522 Naegok-dong, Gangneung, Gangwon-do, 210-701, KOREA
[3] Disaster Prevention Research Department, National Disaster Management Institute, 136 Mapo-daero, Mapo-gu, Seoul, 121-719, KOREA
[4] Dawoo Instituteo of Construction Technology, 60 Songjuk-dong, Jangan-gu, Suwon, Kyonggi-do, 440-210, KOREA

to the front part by installing a piezoelectric element on the outside of the existing harbor structure. The proposed wave power system can be generally applied to a variety of ocean structures so as to add wave power generation function to their original functions.

Furthermore, as it uses Unimorph piezoelectric elements which are easy to handle and cheap, many generators can be installed at relatively low costs and it is also advantageous for large size systems. This paper presents the practical conditions of wave power generation through a hydrographic model test.

PIEZOELECTRIC ENERGY HARVESTING SYSTEM

Piezoelectric Element

Piezoelectric effect refers to the conversion between mechanical energy and electrical energy through the medium of a piezoelectric body. When a pressure is applied to a type of crystal from a certain direction, electrical polarization in proportion to the external force occurs on both sides of the plate.

It was first discovered by the Curie brothers in France in 1880. Later it has been found that even though the piezo-electricity of one crystal plate is weak, if multiple sheets of metal foils are stacked, the quantity of electricity is increased. It was also found that the crystal plate has a natural oscillation and when the elastic oscillation coincides with the electric oscillation, it results in a greater oscillation. The occurrence of electric polarization on the surface of crystal receiving a force is called the piezo-resistance effect.

When crystals such as quartz and Rochelle salt receive a pressure, a voltage is generated, and this is called 'direct piezoelectric effect.' When opposite voltage is applied, the crystal is deformed, and this is called ' inverse piezoelectric effect.' Taking the name from the discoverers, the direct piezoelectric effect is also called 'Curie effect' and the inverse piezoelectric effect 'Liebmann effect.' Furthermore, it is called 'longitudinal effect' if electric charge is generated in the direction of the force applied to the crystal, and 'lateral effect' if it is perpendicular (Jong-Soo Park et al., 2005; So-Nam Yun et al., 2009).

The Unimorph piezoelectric element has a thin circular piezoelectric ceramic plate on a metal vibrating plate. Due to its simple structure and easy handling, it can be mass produced with simple manufacturing process and the manufacturing cost is low.

The specifications of the piezoelectric elements used in this experiment are shown in Table 1 Fig. 1 shows a disc Unimorph type with a disc-shaped thin brass sheet with a circular PZT ceramic attached to one side. Its principle is to use external vibration energy to generate electric output by the piezoelectric effect of ceramic.

Table 1 Piezo element specifications

Specifications	
Section (Unit)	Value
Rated maximum voltage (Vp-p square wave)	30Vp-p
Capacitance	20,000pF ±30%
Resonant frequency	4200 ±500Hz.
Resonant impedance	≥300Ω.
Operating temperature	-20 to +60°C
Storage temperature	-20 to +70°C
Dimensions D ±0.1	31mm
d ±0.3	20mm
t ±0.02	0.3mm
T ±0.1	052mm
Lead wire	28AWG

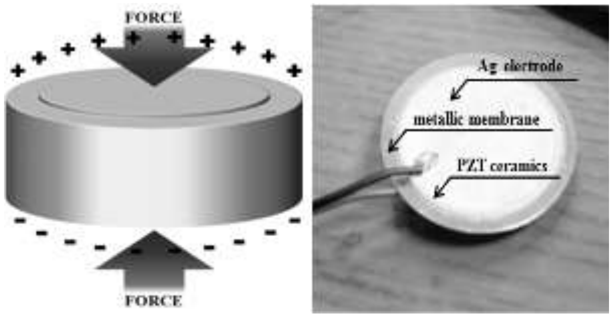


Fig. 1 Piezoelectric effect

Piezoelectric Energy Harvesting System

The piezoelectric energy harvesting system was designed in this study to enable power generation even in areas with small wave energy by directly using wave force and also allow universal application to the existing structures.

For this piezoelectric energy harvesting system, the characteristics of a new type of waver power generation system were devised using the Curie effect by the motion of the piezoelectric element when an external force is applied to the front part of the piezoelectric energy harvesting system and transmitted to the center of the piezoelectric element.

As shown in Fig. 2 the piezoelectric energy harvesting system was manufactured in the shape of a simple beam so that the external force acting on the piezoelectric energy harvesting system would be transmitted to the piezoelectric element.

Furthermore, an elastic rubber was used to prevent the damage of the piezoelectric element to which the external force is transmitted and allow the motion energy will act continuously when there is an external force.

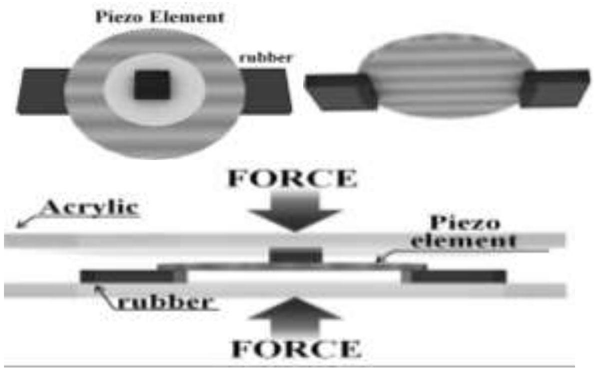


Fig. 2 Concept of piezoelectric energy harvesting system

The piezoelectric energy harvesting system was made with six sets of six piezoelectric elements with a total of 36 piezoelectric elements and was designed in such a way that the system could be attached to or detached from the caisson, as shown in Fig. 3

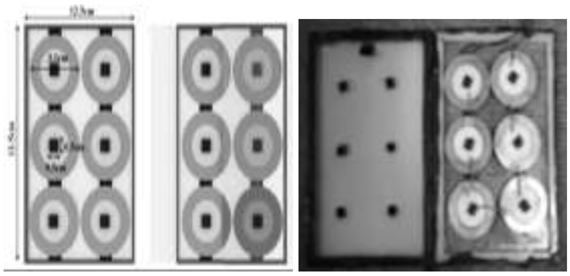


Fig. 3 Piezoelectric energy harvesting system

laboratory of the Waterfront and Coastal Research center of Kwandong University. The wave maker used in this test was an electric servo-piston type which could make both regular and irregular waves.

The cross-section water tank (W:1.0m x L:30m x H:1.5m) was installed to continuously change the cycle and wave height and with tempered glass for both sides of the 30 m section except for 6 m of the wave making unit and wave removing unit for observation of the general trends of the incident waves.

Furthermore this wave maker has a wave height gauge attached to the front of the wave paddle to enable reflected wave absorbing control based on the data read by the wave height gauge. In addition, a wave removal facility consisting of rubbles, Styrofoam, aluminum pieces, and absorption filter was installed to minimize the generation of reflected waves, as shown in Fig. 4

The wave maker used for the 2-D hydrographic test can make irregular waves by spectrum function and regular waves corresponding to the given wave height and cycle. The specifications of the wave generator are shown in Table 2.

Table 2 Specifications of the wave generator

Specifications		
Dimensions of channel		30m(L)×1.0m(W)×1.5m(H)
Wave maker performance	Size of wave paddle	0.695m(W)×1.5m(H)
	Maximum wave height	0.5m
	Wave period	0.5~5.0sec
	Driving method	Electric servo piston type

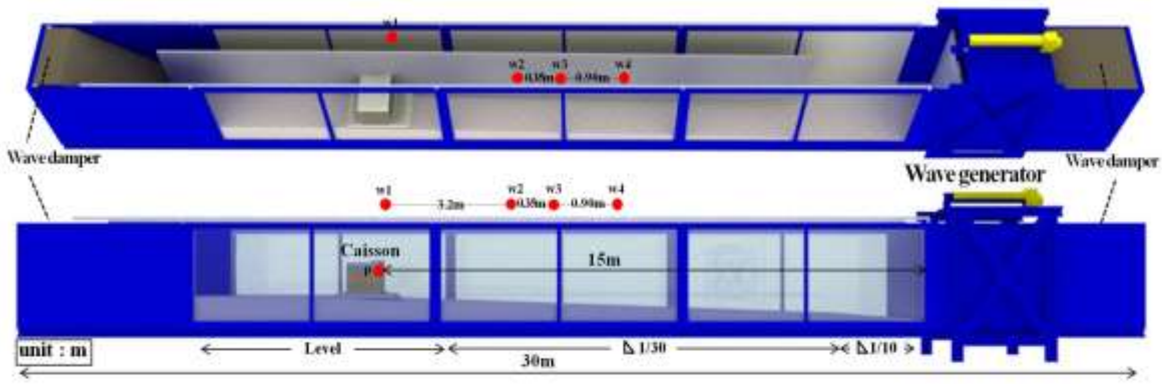


Fig. 4. Schematic section of wave-current 2-D

2-D CROSS-SECTION HYDROGRAPHIC MODEL TEST

Test Outline

The hydrographic model test was performed in a

Experiment Method

For the 2-D hydrographic model test, to evaluate the power generation characteristics of the piezoelectric energy harvesting system, an order-made caisson was installed inside the cross-section water tank to mount the piezoelectric energy harvesting system. The reflectivity, wave pressure, and voltage were examined.

The reflectivity was measured from a capacitive wave height gauge at three points (w2~w4) on the front part of the caisson structure. Furthermore, a wave height gauge was installed at w1 to measure the incident wave height. In Fig.4 the locations from the wave paddle were indicated. To facilitate the measurement of incident wave, the width of the wave channel was divided at 6:4 in longitudinal direction and the structure model and wave height gauge were installed there, respectively. The test wave heights and cycles were analyzed by the zero up crossing method using the reading data between 30 sec – 700 sec after wave making. The measured signals were amplified through the amp and sent to DAQ and the data were stored and analyzed through the computer. DAQ stored data at the sampling rate of 20 Hz. The actual wave height was converted through the calibration coefficient from the volt measured at the wave height gauge and wave pressure meter. Fig. 5 shows the measurement instruments used in this test.

The tests were repeated at least three times under the same conditions before the results were analyzed. For the experimental waves, regular waves were applied, considering the frequency spectrum.

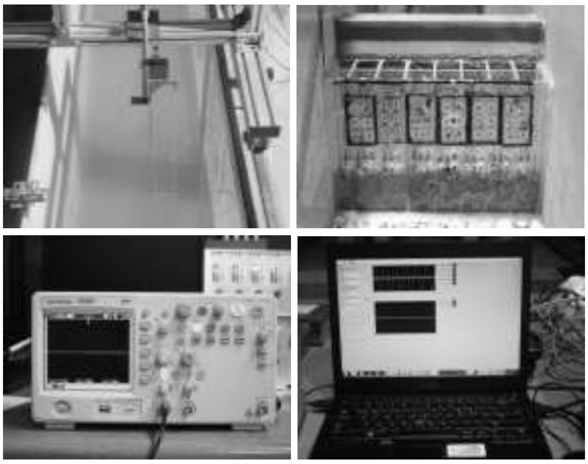


Fig. 5 Photograps of experiment system

As shown in Fig.5 the piezoelectric energy harvesting system installed at the front of the caisson measured the maximum voltage and maximum wave pressure using an oscilloscope and a wave pressure meter.

The experimental conditions of the waves are shown in Table 3.

Table 3 Experimental condition

Case	Water depth h(cm)	Wave height H(cm)	Wave period T(sec)
case01	50.0	1.25	0.47
case02	50.0	1.25	0.63
case03	50.0	1.25	0.79
case04	50.0	2.50	0.63
case05	50.0	2.50	0.79
case06	50.0	2.50	0.95
case07	50.0	3.75	0.63
case08	50.0	3.75	0.79
case09	50.0	3.75	0.95
case10	50.0	5.00	0.95
case11	50.0	5.00	1.11
case12	50.0	5.00	1.26
case13	50.0	7.50	0.95
case14	50.0	7.50	1.26
case15	50.0	7.50	1.58
case16	50.0	10.0	0.95
case17	50.0	10.0	1.26
case18	50.0	10.0	1.58
case19	50.0	12.5	1.26
case20	50.0	12.5	1.42
case21	50.0	12.5	1.58

EXPERIMENTAL RESULTS AND ANALYSIS

To analyze the characteristics of the voltage produced according to the changing wave energy as the first step in the research to add new functions to the existing structures by recovering electricity from the piezoelectric energy harvesting system using waveenergy, a total of 21 regular waves including seven wave heights with different periods and three periods with different wave heights were generated and their characteristics were analyzed. Fig.6 shows the experiment method.

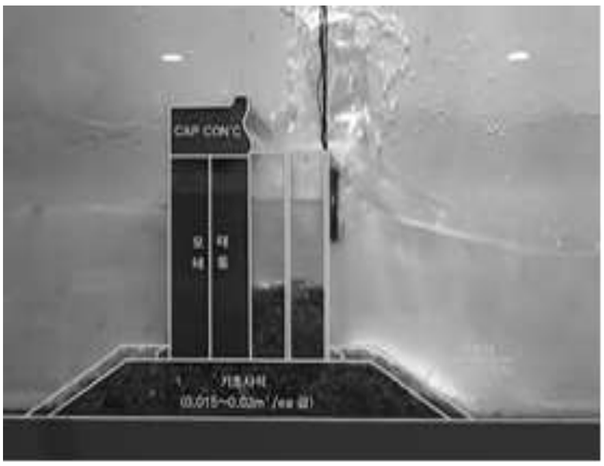


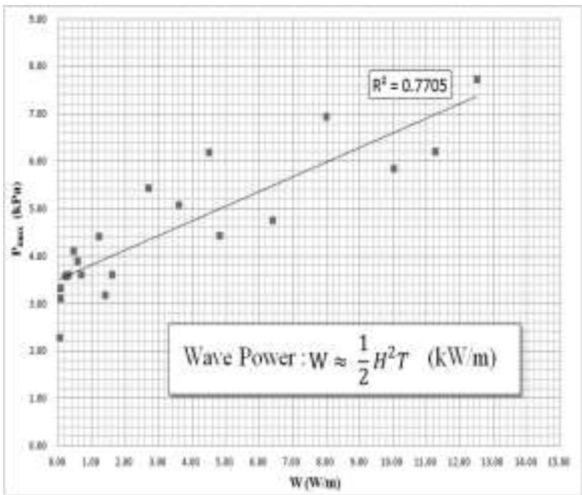
Fig. 6 Ssnapshot of two-dimensional wave flume test

Table 4 Result of the experiment

Case	Wave height H(cm)	Wave period T(sec)	P_max	V_max
case01		0.47	2.3006	3.55
case02	1.25	0.63	3.1228	4.95
case03		0.79	3.3423	5.20
case04		0.63	3.6086	5.70
case05	2.50	079	3.5981	5.34
case06		0.95	3.6187	5.74
case07		0.63	4.1219	6.89
case08	3.75	0.79	3.9217	5.81
case09		0.95	3.6195	5.68
case10		0.95	4.4291	7.29
case11	5.0	1.11	3.1951	4.99
case12		1.26	3.6223	5.87
case13		1.2	5.4501	8.57
case14	7.50	1.26	5.0983	8.13
case15		1.58	6.2146	9.84
case16		1.2	4.4527	7.32
case17	10.0	1.26	4.7813	7.23
case18		1.58	6.9499	10.32
case19		1.26	5.8604	9.33
case20	12.50	1.42	6.2315	9.81
case21		1.58	7.7471	11.24

According to the results of the hydrographic test, as shown in Fig. 7 as the wave height and period increased, the wave energy and the maximum wave pressure increased, which in turn increased the maximum voltage. In other words, when wave energy is activated on the front of the piezoelectric energy harvesting system, this force is transmitted to the piezoelectric element, thus giving rise to the Curie effect and voltage.

Furthermore, it was verified that as the wave energy increased, the maximum wave pressure was positively proportional to the maximum voltage.



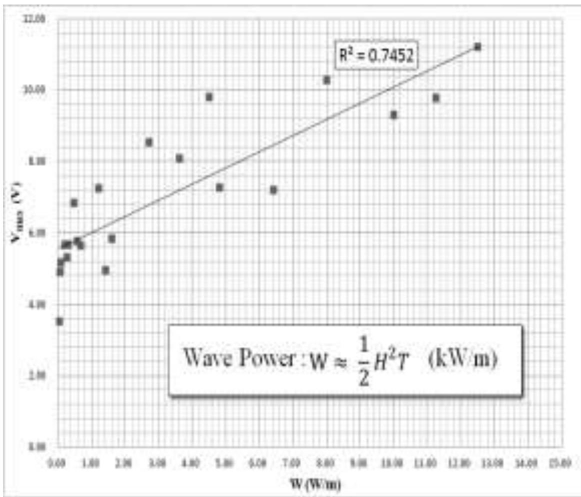


Fig. 7 Maximum wave pressure (red) and voltage (blue) as a function of wave power

As the representative result, a 11.24V voltage was generated when Ho=12.5cm and To= 1.58sec.

CONCLUSION

In this study, to develop a new wave power generation technology using the piezoelectric elements that can be generally applied to all the existing harbor structure, a hydrographic model test was conducted to identify the shape and basic characteristics of the generator and analyze its tendencies. The possibility of applying wave power generation using piezoelectric elements was verified.

The findings from this study are summarized as follows:

The greater the wave height and period was, the greater the wave energy became, which increased the maximum wave pressure and the maximum voltage also increased.

As the wave force applied to the front of the piezoelectric energy harvesting system increased, the voltage generated in the system increased proportionately.

For this study, the piezoelectric element test scaled down the local waters and caisson size to 1:40 by the Froude law of similarity, but the piezoelectric energy harvesting system could show its maximum efficiency because it was not scaled down.

Therefore, more studies will be conducted to propose the optimum shape and maximum power generation efficiency of the piezoelectric energy harvesting system.

ACKNOWLEDGEMENTS

This work was supported by the Regional Innovation Center Program at Kwandong University of the Ministry of Knowledge Economy and a Manpower Development

Program for Marine Energy by the Ministry of Land, Transport and Maritime Affairs (MLTM).

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