Disaster mitigation based on smart structures/materials

H. Asanuma*[a], J. Su[b], M. Shahinpoor[c], F. Felli[d], A. Paolozzi[e, f], M. Nejhad[g], L. Hihara[g], S. Aimmanee[h], Y. Furuya[i], K. Adachi[j] and T. Yanaseko[a]
[a]Dept. of Mechanical Engineering, Chiba Univ., 1-33 Yayoicho, Chiba-shi, Japan 263-8522; [b]Advanced Materials and Processing Branch, NASA Langley Research Center, Hampton, VA, USA 23681-2199; [c]Dept. of Mechanical Engineering, Univ. of Maine, Orono, ME, USA 04469-5711; [d]Dept. of Chemical Engineering, Materials and Environment, Sapienza Univ. of Rome, Via Eudossiana, 18, 00185 Rome, Italy; [e]School of Aerospace Engineering, Sapienza University of Rome, Via Salaria, 851, 00138 Rome, Italy; [f]Centro Fermi, Via Panisperna 89, Rome, Italy; [g]Dept. of Mechanical Engineering, Univ. of Hawaii at Manoa, 2540 Dole Street, Honolulu, HI, USA 96822; [h]Dept. of Mechanical Engineering, King Mongkut's Univ. of Technology Thonburi, Thung-Khru, Bangkok, Thailand 10140; [i]North Japan Research Institute for Sustainable Energy, Hirosaki Univ., 2-1-3 Matsubara, Aomori-shi, Japan 030-0813; [j]Dept. of Mechanical Engineering, Chubu Univ., 1200 Matsumotocho, Kasugai-shi, Japan 487-8501

ABSTRACT

The concept "Disaster Mitigation and Sustainable Engineering" is introduced comprehensively and several examples are shown in this paper. It is emphasized that it can be effectively realized in the field "smart materials and structural systems." As serious disasters may not occur for a long period of time, and the structures for disaster mitigation suffer from vast amount of maintenance cost etc., they are better to be used daily. Their compactness and deploying function are also very useful. In order to demonstrate the concept, two examples having been experimentally tried are introduced, that is, artificial forests and deployable structure based on honeycomb to be used against flooding. Other examples and products in the world are also introduced and future directions are discussed.

Keywords: disaster, tsunami, flooding, sustainability, deployable structure, energy harvesting, daily use

1. INTRODUCTION

In recent years, more serious disasters occur around the world than in the past, and a large number of people are lost in spite of the rapid advancement of science and technology. In order to solve this problem, disaster mitigation to be realized by novel ideas and technologies is of increasing importance and the authors et al. are thinking of building a platform to create novel technologies and products by involving enthusiastic people from various fields based on advanced science and technology such as "smart materials and structural systems." The authors et al. have proposed the new concept "Disaster Mitigation and Sustainable Engineering" which enables sustainability as well as disaster mitigation, effectively and economically. It is emphasized that this novel concept can be effectively realized by the innovative field "smart materials and structural systems," which has been fostered for more than 20 years and continuously paid attention as a new emerging and attractive interdisciplinary field. From its early stage, variety of related sessions have been organized as a part of JSME (The Japan Society of Mechanical Engineers) activities as well as Intelligent Materials Forum and so on of The Society of Non-Traditional Technology, SPIE, ASME, AIAA, ICAST, IWSHM, CANSMART, SMN, CIMTEC and some other ones. Especially, the number of presentations at JSME annual meeting (MECJ) has been increasing, and it has also become a nucleation site for developing new innovative fields. A couple of research committees have been managed for many years, and as one of them, "Active Material Systems" Technical Section which belongs to the M&P (Materials and Processing) Division of JSME has been playing an

*asanuma@faculty.chiba-u.jp; phone +81-43-290-3201; fax +81-43-290-3039;

Sensors and Smart Structures Technologies for Civil, Mechanical, and Aerospace Systems 2016,
edited by Jerome P. Lynch, Proc. of SPIE Vol. 9803, 980302 · © 2016 SPIE
CCC code: 0277-786X/16/$18 · doi: 10.1117/12.2222153

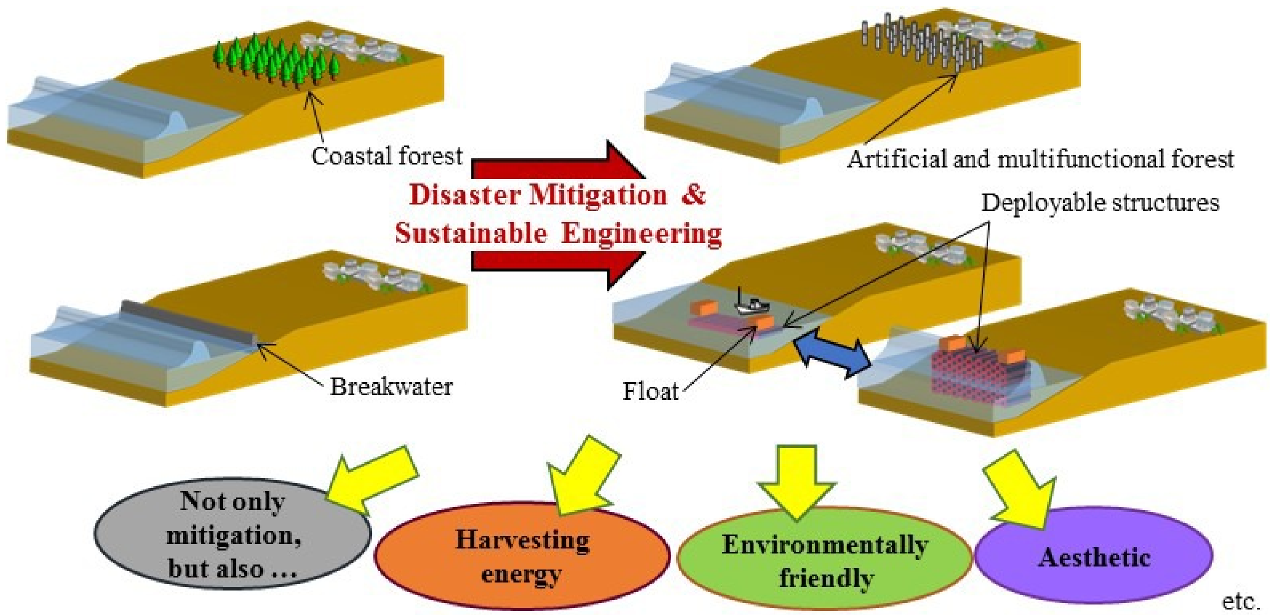


Figure 1. Typical examples to show the concept of "Disaster Mitigation and Sustainable Engineering."

important role to support and activate the field. Generally, its major applications have been explored in mechanical, electronics, civil, architecture, aerospace, automobile, transportation, biomedical, and so on. But, since the Japanese earthquake and tsunami disasters on March 11, 2011 [1], Asanuma et al. had proposed a new concept and have been exploring a completely new and effective direction for disaster mitigation.

2. DISASTER MITIGATION AND SUSTAINABLE ENGINEERING

The new concept "Disaster Mitigation and Sustainable Engineering" can be briefly explained using the typical examples shown in Figure 1 and Figure 2. Serious disasters may occur today or may not for a long period of time. The structures necessary for disaster mitigation need vast amount of construction and maintenance costs. So, we better think of using them daily to produce something useful such as energy. The generated energy can be used for their monitoring, maintenance, corrosion suppression, repair, and many other purposes such as lighting, charging drones, and so on. The disaster mitigation devices and structures have to be available even if disaster occurs once for hundred years. For the overwhelming period without disasters, they are not necessary from disaster mitigating point of view, so their compactness is very useful from daily and aesthetic point of view. In addition, a "Smart Furniture" to protect valuable products from falling from shelves etc. at the time of earthquake has been considered. Asanuma et al. introduced the concept etc. at the Chiba University symposium on January 26 and also at the MECJ-12 on September 11, 2012 [2, 3]. In addition, several invited talks etc. such as keynotes at MECJ, MRS-J and PT-PIESA 2013 have been delivered by Asanuma [4, 5 and 6].

Asanuma, Furuya et al. are establishing a research committee with Nonami, Maeno, Yamazaki, Igarashi, Kudo, Takahashi, Shimazu, Sumantyo, Kubo, Maruyama, Takei, Tanaka, Lu, Koyama, Okawa and several more members from Chiba University, and Kishimoto (NIMS), Furukawa (Yamagata University), Nakao (Yokohama National University), Kosaka (Kochi University of Technology) et al., and the authors, Vendittozzi (Univ. of Brasilia), Dry (Natural Process Design) et al. are also extending it to be more international one.

First of all, in order to explain the concept more comprehensively, two examples having been experimentally done are mainly introduced and discussed. As the first example, an artificial forest has been developed, which are intended to have better capability of high wave or tsunami mitigation than actual ones [7, 8], by optimizing various parameters such as configuration, density and material. Natural forests have many problems such as low fraction of trees, low visibility of ocean waves, low strength, long time to grow, and so on. The first two experimental parameters have been mainly

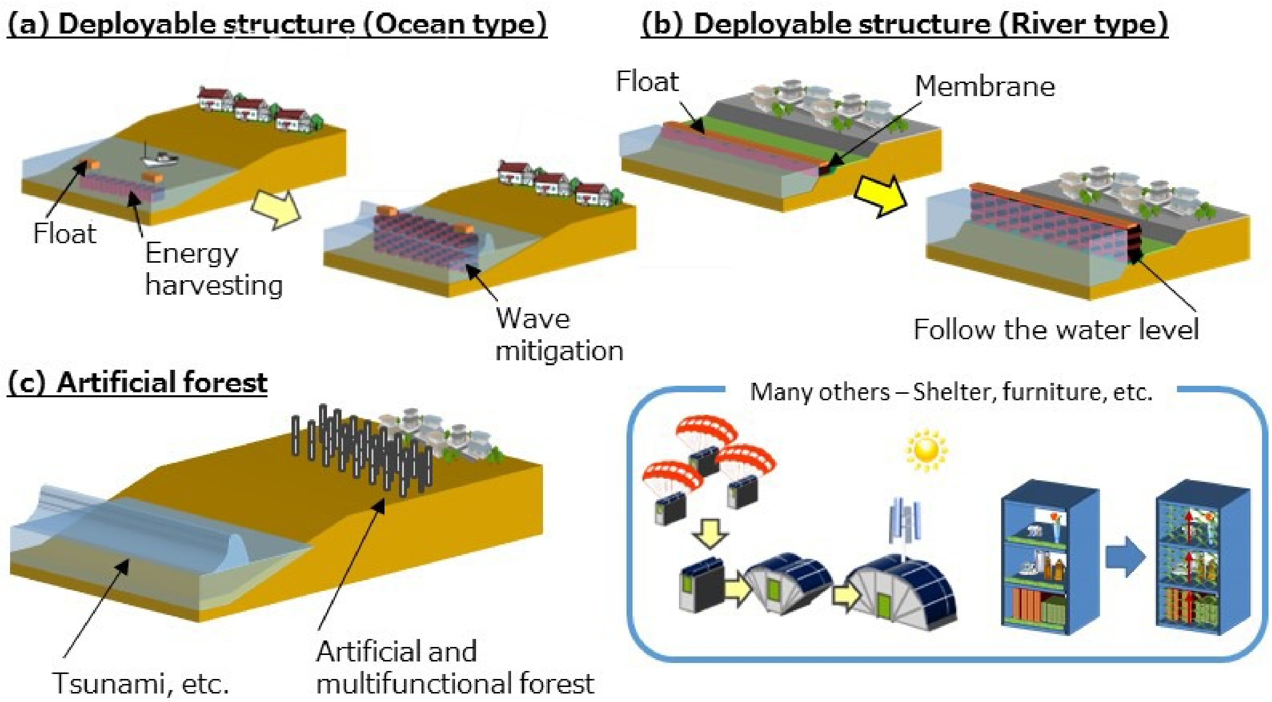


Figure 2. Examples to realize the concept.

examined by using a water channel set-up prepared for this research. Multifunctional design is also described. As the second example, a new smart structure based on honeycomb like one to be used against flooding etc. is proposed and demonstrated to show the possibility of autonomously deployable due to increase of water level as external environmental change. This autonomous height-controlled river or anti-flooding bank system can be regarded as a smart structure. Energy harvesting materials and systems are under consideration and development to make the system much smarter and fully realize the concept.

Secondly, several challenges toward future mostly done by the authors, and several smart products from industries and projects are introduced, and finally, the content is summarized

3. EXPERIMENTAL AND FUTURE WORKS

3.1 Artificial forests [9]

An aquarium as shown in Figure 3, consisting of 300 mm wide and 4500 mm long waterway and hydraulic bore water tank, was used, and an artificial forest model, consisting of 4 mm diameter and 300 mm long columnar poles, was arranged as shown in Figure 4, where lattice spacing S and number of rows N were changed. It was placed in the range of 2780 to 3180 mm from the gate of water tank. Stage type wave was generated by setting the initial water height of the waterway h_o = 30 mm and the initial water height of the water tank H = 240 mm, and opening the gate. In this case, the generated hydraulic bore is the state of supercritical flow, of which flow rate is 1.5 m/s and Froude number is 1.5 at the front edge (tank side) of the model.

To observe the state of flow passing through the artificial forest model, photos were taken from the above and the side positions with a digital camera. Then, by using an image processing software, flow rate and water level at the front and the end of the pole group model were measured, and reduction of those were used to evaluate wave mitigation effect .

From the preliminary studies [10], the arrangement shown in Figure 4 is better than square one, and smaller spacing S is also better. Therefore, the effect of type of material, that is, aluminum alloy (A2017-T4) and stainless steel (SUS304) were compared as a function of number of rows N from 1 to 12 at the minimum and constant S (= 15).

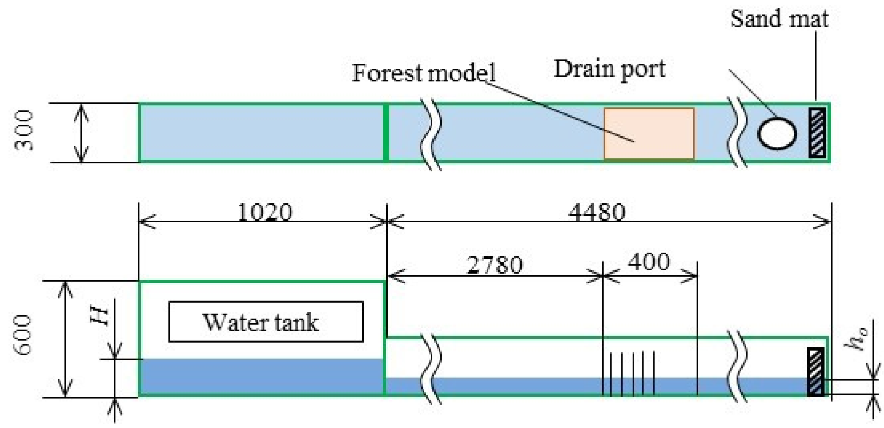


Figure 3. Schematic of experimental waterway.

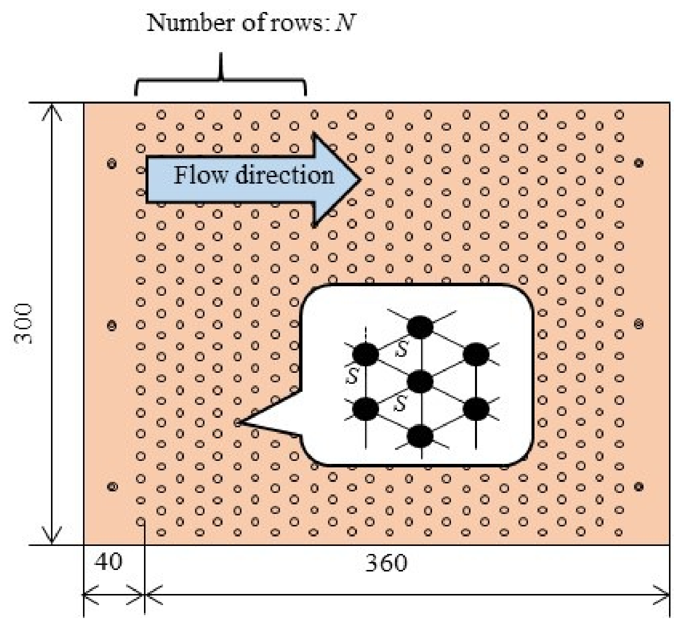
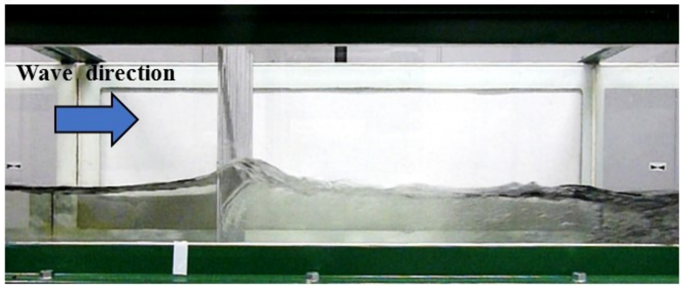


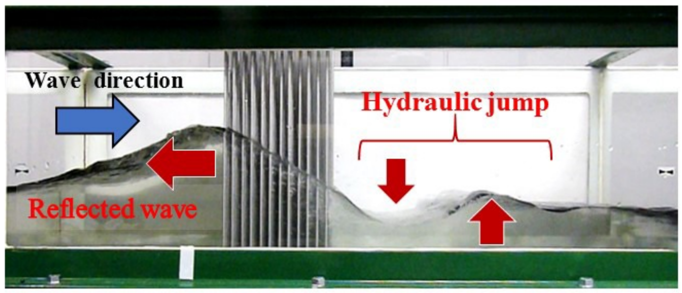
Figure 4. Schematic of metal plate to arrange poles.

In Figure 5, the water flow interacting with the artificial forest model made of A2017 poles is shown. In the case of N = 12, remarkable reflection of the incident wave can be observed in front of the model, and remarkable reduction of the water level and hydraulic jump phenomenon can be observed behind it.

In Figure 6, reduction rate of water flow velocity as a function of number of rows is shown. According to the figure, the reduction rate increases with increasing number of rows for both materials, and those of A2017 are generally higher than those of SUS304 except N = 1 and 2. This tendency is considered to be caused due to the difference of Young's moduli of the materials, that is, A2017 having lower Young's modulus can absorb the kinetic energy of water flow. Lower rigidity materials such as polymeric may be also promising. In order to add functions, coatings of functional materials on the poles are planned.



(a) $N = 1$



(b) $N = 12$

Figure 5. Side views of water flow experiments using A2017 poles of number of rows (a) $N = 1$ and (b) $N = 12$.

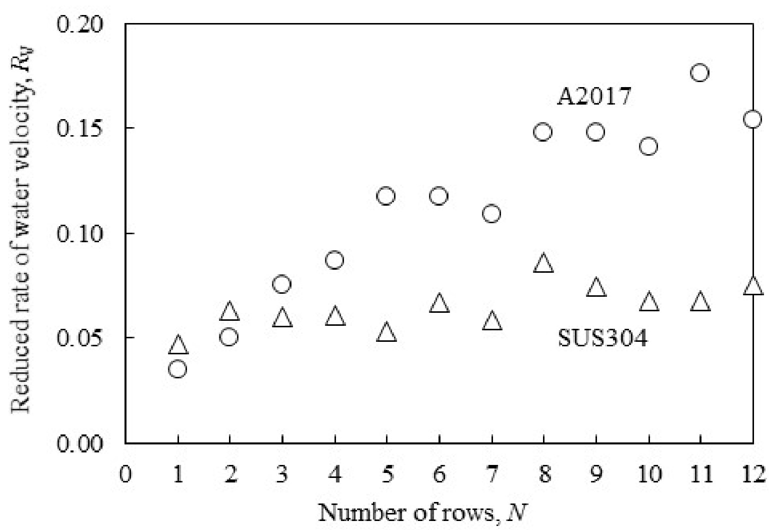
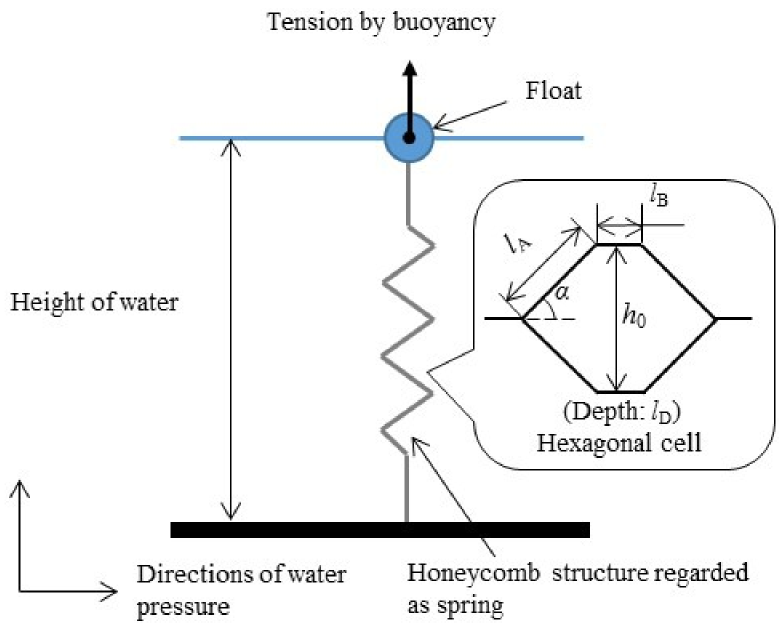


Figure 6. Effect of number of rows N on reduction rates of water velocity R_V for the cases of A2017 and SUS304.

As the next step of this research, the poles are planned to be integrated with voltage generation or energy harvesting function using vibration of the poles due to air flow and/or water flow. To realize this, electroactive polymers, piezoelectric materials [11, 12], etc. are under investigation to be applied, or conventional electro-mechanical systems can be used for a while [13, 14, 15 and 16].



t /mm	0.2
α /deg	5
h_0/mm	10
l_A /mm	50
l_B /mm	20
l_D/mm	10

Figure 7. Schematic of deployable structure model.

3.2 Deployable structure [9]

In Figure 7, a schematic drawing of the deployable honeycomb structure model is shown. In this study, the cell shape was designed based on the assumption that the cell is made of 0.2 mm thick aluminum (A1050-H24) and can elastically deform up to the double of its original height.

In Figure 8, a schematic diagram of the force measurement test is shown. The model was fixed to the aluminum flat pole attached on a universal tester (Shimadzu Corporation AG-10kNI), and was deformed by tension/compression cycle test, which corresponds to 10 mm expansion from the initial height at the testing speed of 1 mm/min.

In Figure 9, the results of load-displacement curves obtained from the cycle tests are shown. There remains no plastic strain after the cycle test, and it is clear that the deformation path is reproducible. In addition, a stack type model consisting of 12 layers was also made, which showed similar deformation and was used for making the model deployable in the water channel.

The preliminary model shown above and the measurement result were used to make the actual model designed to follow the height of water level with a float (POM pole) to lift the model and a membrane (PVC) to stop water flow, which are attached to L-shape aluminum frames on both vertical sides of the structure to obtain higher stiffness in the direction of water flow. This model was set in the same water channel as used for the artificial forest experiment and water was supplied at the rate of 1.3 l/s up to 150 s where overflow started. Then the water flow was stopped and the water level reduced. The heights of the water level and the top of the structure were measured.

In Figure 10, the actual model is shown at the initial and the successfully deployed states, and the relationship between the height of structure and the height of water is shown in Figure 11. According to the figures, it is clearly observed that the structure can be deployed by the water and its height is following the water level up to the upper limit of 150 mm, where the water flow can be blocked. Above this level, the supplied water overflowed. This system can be regarded as a smart structure because its height is found to be in autonomously proportion to the water height and its change as an environmental state in the experimental range.

As the next steps of this research, the authors are trying to embed functional materials such as piezo-composites and IPMCs to make the structure multifunctional and smarter.

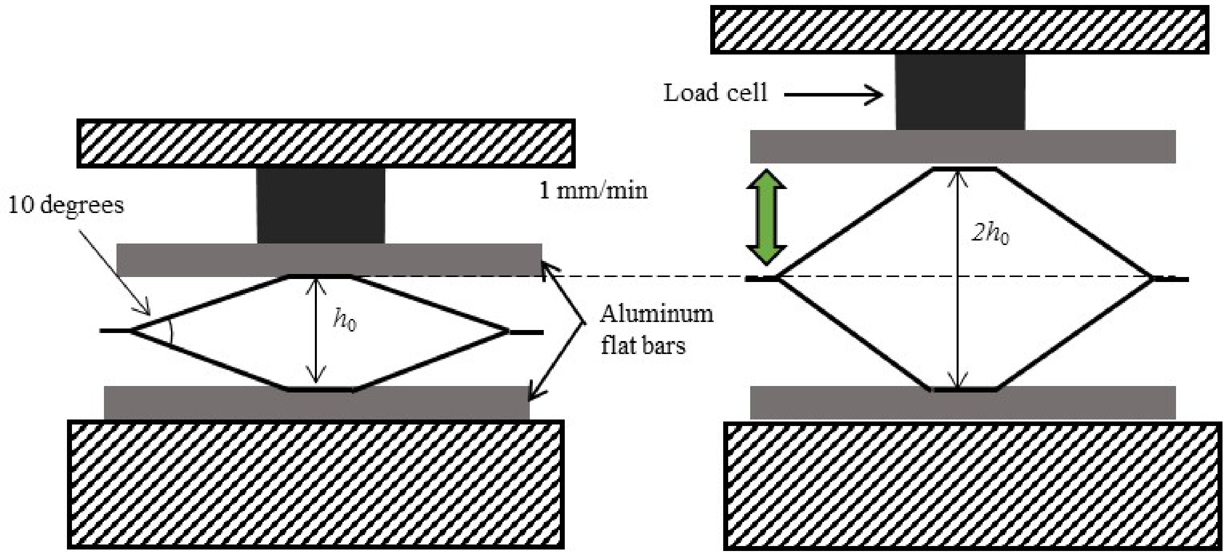


Figure 8. Schematic of force measurement system.

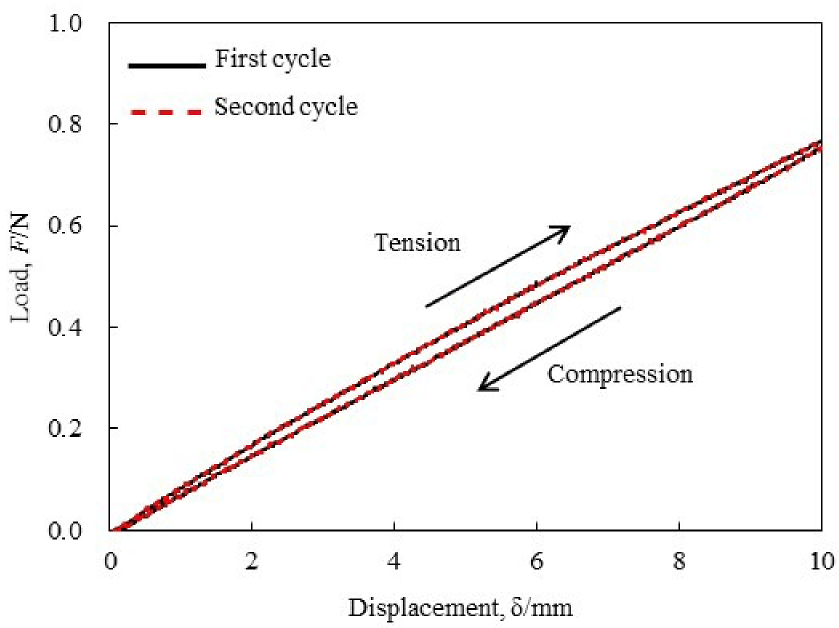
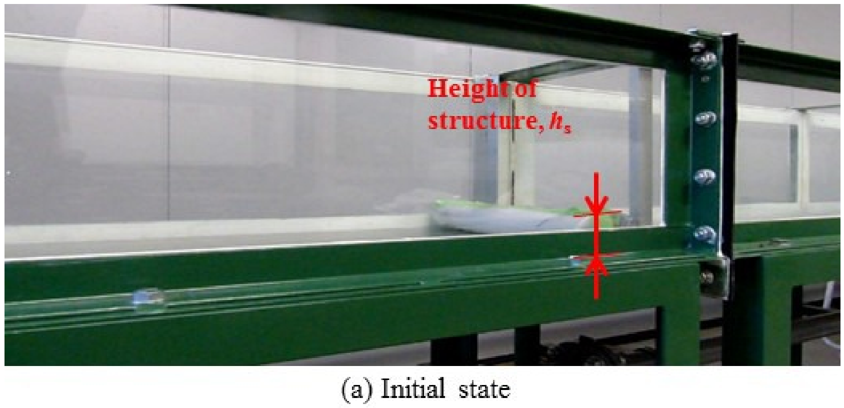


Figure 9. Results of load-displacement curves obtained from the cycle test.



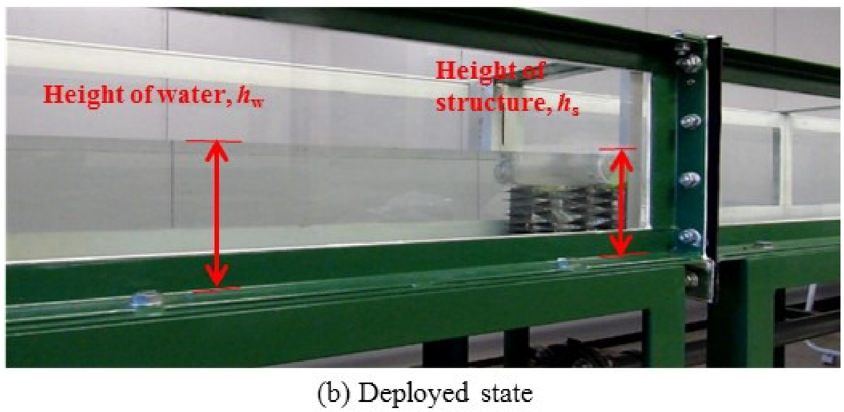


Figure 10. The actual deployable structure model at (a) initial and (b) deployed states.

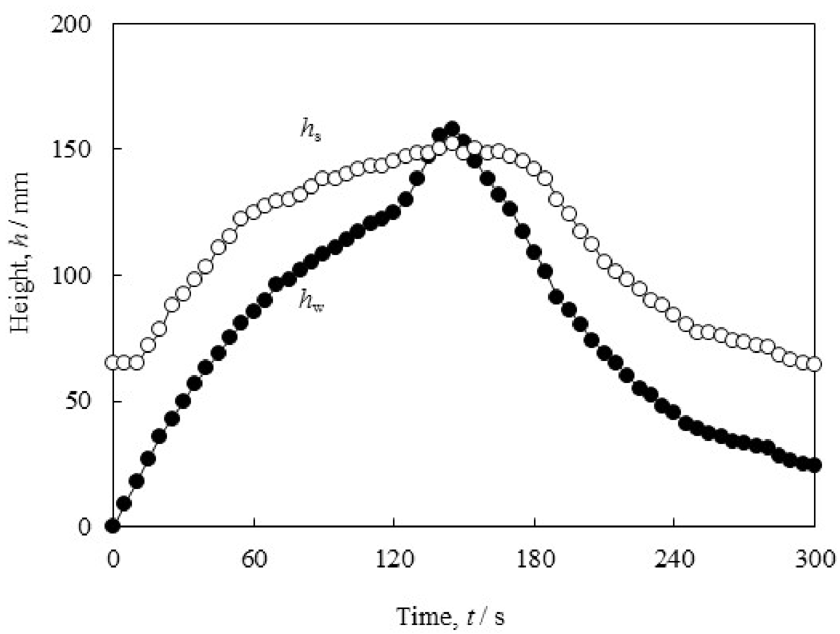


Figure 11. Relationship between the heights of structure h_s and water h_w.

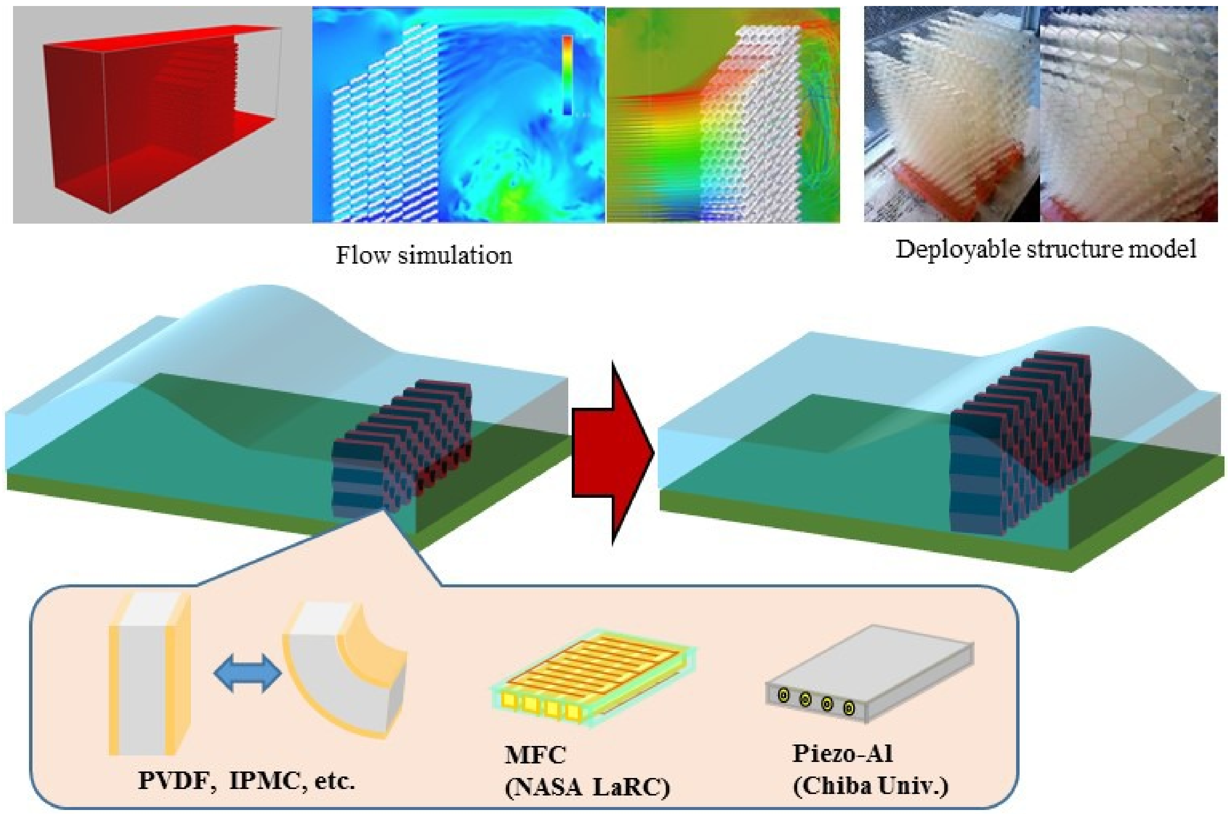


Figure 12. A new design of tsunami barrier using computational fluid dynamics (CFD), and its next plan to be multifunctional.

3.3 Challenges toward future

The following researches are mainly undergoing by the authors et al.
1) Applications of Piezoelectric Polymers in Electrical Power Generation Using Ocean Waves [17].
2) Dynamic Deployment of Smart Inflatable Tsunami Airbags (TABs) for Tsunami Disaster Mitigation [18].
3) A Novel Underwater Inflatable Structures for Smart Costal Disaster Mitigation [19].
4) Structural Health Monitoring of Pipelines for Environment Pollution Mitigation [20].
5) The Contribution of LARES to Global Climate Change Studies with Geodetic Satellites [21].
6) Smart Disaster Mitigation in Italy [22].
7) Smart Disaster Mitigation in Thailand.

The following one is also undergoing. In order to cope with tsunami, rigid and fragile structures are not suitable, and rather strong, light and flexible structures are preferred, Asanuma et al. have started to develop a multi-layered flexible and deployable structural material system to diminish the force of tsunami and dissipate its energy by separating water flow and letting them conflict with each other as briefly shown in Figure 12 [23], which was presented as a part of the plenary lecture at the International Innovation Workshop on Tsunami, Snow Avalanche and Flash Flood Energy Dissipation (January 21-22, 2016, Lyon, France) where lots of innovative ideas and challenges such as offshore mega-floating structures with energy harvesting function as well as dissipation function were introduced and future works were discussed [24].

There are many more related researches. For example, a novel concept for bonding components of the smart structures aiming at high specific strength and long term durability was proposed by Asanuma and some experiments are undergoing with a couple of companies. A corrosion testing of the bonded samples is also started in collaboration with Hihara and Sugamoto from Univ. of Hawaii at Manoa.

Fig.13 The neo RiSe land-mounted flap gate embankment system (Courtesy of Mr. K. Nakayasu (Hitachi Zosen Corporation)).

4. SMART PRODUCTS FROM INDUSTRIES AND PROJECTS

Various challenges have been done in industries and some are already commercialized. The following products are attractive and can be considered to be smarter.

In Figure 13, one of the products successfully developed by Hitachi Zosen Corporation is schematically shown. The neo RiSe® (no energy, no operation, Rising Seawall) land-mounted movable flap-gate type seawall can be autonomously deployed by using the force of tsunami [25, 26].

Project MOSES [27, 28], Aqua Dam [29], Inflatable Flood Barriers [30], Inflatable Rubber Dam [31], Water-Gate [32] are also attractive examples.

In addition to the above mentioned products, Takenaka Corporation proposed innovative "Breakwater and breakwater group [33]."

5. SUMMARY

New ideas and developments for smart disaster mitigation toward future especially based on smart structures/materials are described in this paper. The proposed concept "Disaster Mitigation and Sustainable Engineering" is the key and explained more comprehensively. Two examples having been tried experimentally to realize the concept are shown. As the first example, artificial forests are examined to have better capability of high wave or tsunami mitigation by changing various parameters such as configuration, density and material. Multifunctional design is also mentioned. As the second example, a novel deployable structure based on honeycomb to be used against flooding etc. is proposed and demonstrated to be autonomously deployable due to increase of water level as external environmental change. This autonomously height-controlled river or anti-flooding bank system can be regarded as a smart structure. Energy harvesting materials and systems are under consideration and development to make the system smarter and fully realize the concept. Many other smart challenges and products are also introduced and future directions are discussed.

ACKNOWLEDGMENTS

The authors thank Mr. K. Nakayasu (Hitachi Zosen Corporation) for his kind offer of valuable information, and also thank Mr. S. Okabe, Mr. Y. Hirayama, Mr. T. Koseko, Mr. H. Suzuki, Mr. D. Katayama, Mr. M. K. Qayyum, Mr. T. Matsumiya and Mr. K. Matsumoto (Chiba University students) for their contributions to collecting information and preliminary experimental works.

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