IPA News Letter Volume 7, Issue 2 June 2022

Special Contribution

Research Projects at National Institute of Maritime, Port and Aviation Technology, Japan, for Achieving Carbon Neutrality

Yoshiaki Kuriyama

President
National Institute of Maritime, Port and Aviation Technology

ABSTRACT

To meet the target of carbon neutrality by 2050 in Japan, the National Institute of Maritime, Port and Aviation Technology (MPAT), Japan, is conducting research activities in various fields such as offshore wind farm, zero-emission ship, blue carbon and air traffic management. For the floating type offshore wind farm, a feasibility study of spar type floaters for a 15 MW wind turbine was carried out. To estimate a damage probability of a wind turbine as required by a new international standard, MPAT proposed a methodology and presented some calculation results. For the bottom-type offshore wind farm, the technical issues mentioned below were numerically investigated: the seismic stability of a monopile type wind turbine, the behavior of an open-ended pile penetrating the ground, and the dynamic response of a monopile to wind and wave. Blades of an offshore wind turbine may disturb signals from a radar for electronic navigation. MPAT examined its potential using model tests. The vessels containing suspended loads for an offshore wind farm project behave differently from those without the loads, and hence the movement of a vessel with a suspended load in the air and in the water were examined. To reduce the amount of carbon dioxide (CO_2) emitted from ships, the use of ammonia and hydrogen as fuel as well as the injection of air bubbles from the bottom of a ship was investigated. Blue Carbon is CO_2 stored in ocean and coastal ecosystems. The amounts of CO_2 taken by shallow water ecosystems across the globe and in Japan were estimated. Before landing, an airplane descends stepwise and consumes fuel during the level flight to maintain its altitude. To reduce the amount of CO_2 emitted for landing, MPAT proposed a fixed flight-path angle descent and confirmed its usefulness.

Keywords: carbon neutrality, offshore wind farm, zero-emission ship, blue carbon, air traffic management, MPAT

1. Introduction

The Japanese Government declared in 2020 that Japan will achieve carbon neutral by 2050. To tackle with this challenge, our research institute, the National Institute of Maritime, Port, and Aviation Technology (MPAT), is carrying out research projects in various fields including offshore wind farm. In this article, after briefly introducing MPAT, I will describe the outlines of some of the research projects.

2. National Institute of Maritime, Port and Aviation Technology (MPAT)

MPAT was established on April 1, 2016, by merging the National Maritime Research Institute (NMRI), the Port and Airport Research Institute (PARI), and the Electronic Navigation Research Institute (ENRI). Our mission is to implement research and development for strengthening the international competitiveness of transportation industry, enhancing the use of oceans, and preserving the coastal and marine environment.

3. Research projects toward carbon neutrality

3.1 Offshore wind farm

The amount of carbon dioxide, CO_2, emitted in the power industry is not small, and thus the development and deployment of offshore wind farms are highly expected. Offshore wind farm is classified into two types according to its supporting structure: floating and bottom-fixed types, which are suitable where the water depth is larger and smaller than 60 m, respectively. MPAT experimentally and numerically examined various challenges of both types.

a) Floating type

The floating type offshore wind farm is further classified into four types: barge, semi-submersible, spar, and tension leg platform types.

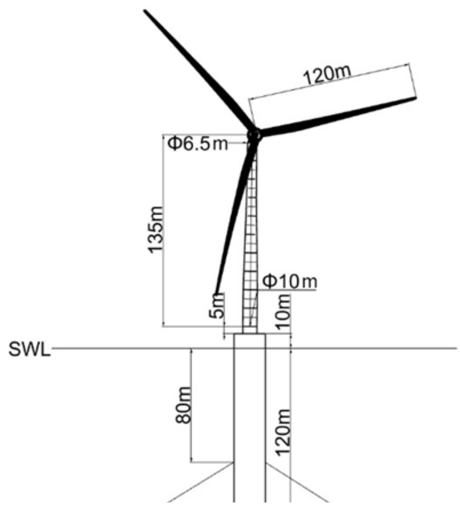


Fig. 1. Proposed spar for 15MW turbine (from Kuroiwa and Chen, 2021)

A feasibility study was conducted on spar type floaters for a 15 MW wind turbine, which is the largest turbine proposed to date. In this study, two floaters made of concrete and steel were studied. Targets for inclination were set to be smaller than 3 and 5 degrees for the static and dynamic inclinations, respectively. Also, a target for natural period was set to be larger than 20 s, to reduce inclination of the spar in waves. Structural strength was evaluated against bending moment of the spar and pressure of sea water. The evaluations of the inclination, natural period and strength were made by analytical methods or numerical simulations. For both types of floaters, suitable structural dimensions which fulfill the targets and the strength were found (**Fig. 1**).

One of the two conditions that International Electrotechnical Commission (IEC) Technical Specification (TS) requires for not necessarily taking into account the damage stability of an unmanned floating offshore wind turbine, is that "The joint probability of loss of stability and subsequent total loss of the structure does not exceed the probability of failure corresponding to the safety level used for assessing the structural integrity of the structure." As the joint probability, MPAT proposed the product of the probability of collision with cruising ships around a floating offshore wind turbine and that of structural total loss due to the ship collision. As trial calculations, the former value was obtained using Automatic Identification System (AIS) data, and the latter was estimated using an FEM model and multi-body dynamics analysis.

b) Bottom-fixed type

The bottom-fixed type offshore wind farm is classified into four types: gravity, monopile, tripod, and jacket types.

To examine the seismic stability of a monopile type wind turbine, a simulation program for coupled analysis of wind and earthquake loads was developed. The developed program is based on finite element analysis (FEA) and models a wind turbine as the combination of beams and nonlinear Winkler springs. In a simulation, first, the seismic response of ground during an earthquake is estimated by an external program that is able to reproduce the details of soil liquefaction. Second, the estimated response of ground is transferred through the soil-structure interaction springs to the next calculation for the structure, in which its displacement and bending moment are estimated. Some of the simulation results for a 2 MW wind turbine showed that the estimated bending moments of the pile were smaller than those obtained by combining the values separately estimated using the wind and earthquake loads (**Fig. 2**). This result indicates that the wind suppressed the movements of the wind turbine caused by seismic motion and hence suggests that the accurate simulation leads to more economical design of pile. The estimated bending moments were also smaller than those estimated by not considering the liquefaction. The liquefaction-induced flow in a sloping stratum caused a non-negligible force acting on the pile.

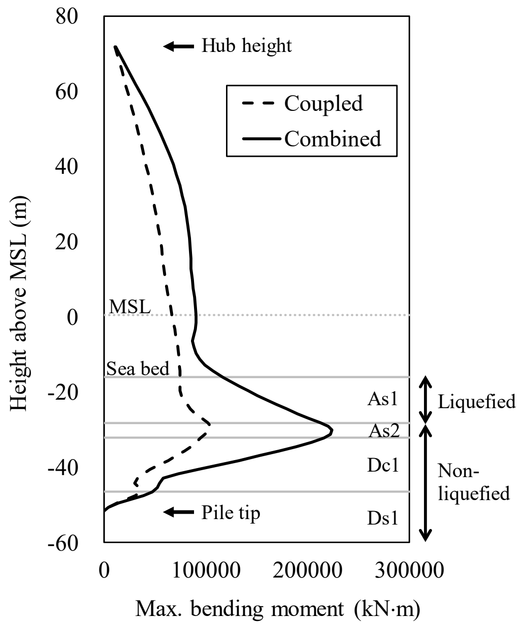


Fig. 2. Comparison of maximum bending moment.

The diameters of monopiles for offshore wind turbines are generally much larger than those for other infrastructures, and the characteristics of the lateral resistance of such large diameter piles are not well understood. In order to estimate the lateral capacity of such piles, it is necessary to accurately predict the ground deformation caused by pile driving. Hence, MPAT simulated the behavior of an open-ended pile penetrating the ground quasi-statically and the stress induced by the pile penetration using material point method (MPM). For this simulation, the frictional contact algorithm in which a rigid body is incorporated in MPM was newly developed. The pile was treated as a rigid body, and the ground was discretized by the particles of the MPM. One of the simulation results successfully represents the soil plugging as shown in **Fig. 3**, which is an important phenomenon in pile driving. In the next step, the effect of pile diameter on the lateral resistance will be investigated.

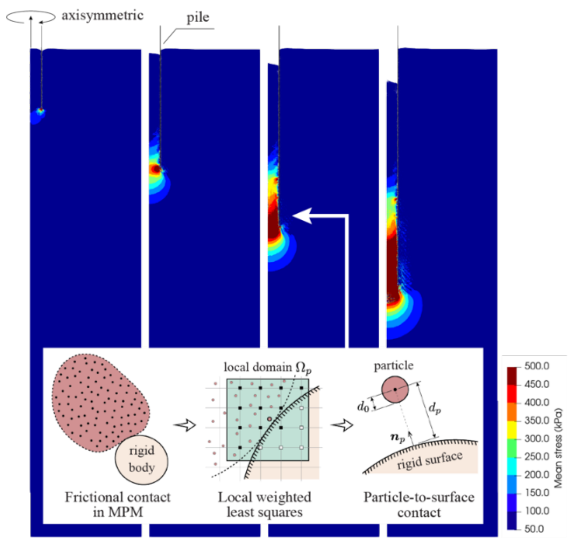


Fig. 3. Mean stress caused by pile penetration simulated using MPM and its frictional contact algorithm (from Nakamura et al., 2021)

The dynamic response of a monopile type offshore wind turbine to wind and wave was tested using the numerical simulation code called FAST (Fatigue, Aerodynamics, Structures, and Turbulence) developed by National Renewable Energy Laboratory in USA, which couples wind and wave forces. The simulation results for a 5 MW wind turbine at a water depth of 20 m show that the wave-induced bending moment took place at the sea bottom, depended on the wave height rather than the wave period, and became large for waves just before breaking in the shallow water region, in which the water-depth-wave-length ratio is below 0.5 (**Fig. 4**).

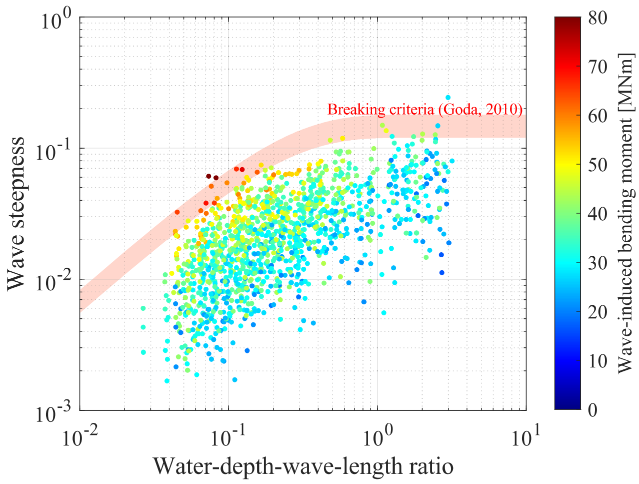


Fig. 4. Occurrence of wave-induced bending moment at a wind speed of 8 m/s

c) Influence of blade on electronic navigation system
The positions of airplanes are detected using signals from VHF omni-directional radio ranges (VORs) and radars. Those signals may be disturbed by the blades of an offshore wind farm. Hence, model experiments for a 2.3 MW wind turbine at scales of 1/144 and 1/72 were carried out in a large anechoic chamber (32 m × 6.2 m × 4.2 m, **Fig. 5**). One of the results showed that in some conditions, the signals from a radar were scattered by the rotating blades, which indicates that the potential scattering should be tested in planning an offshore wind farm.

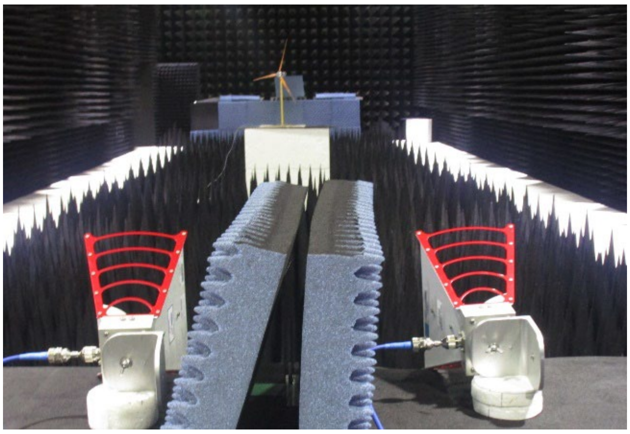


Fig. 5. Measurement setup for radio scattering by the rotating wind turbine

d) Vessel movement with suspended load
For construction, operation, and maintenance of an offshore wind farm project, vessels load, transfer, and unload materials. The vessels containing suspended loads behave differently from those without the loads, and hence the movement of a vessel with a suspended load in the air and in the water were examined in laboratory experiments, in which the model scale was 1/30 and the displacement and the immersed load weight were 6129 t and 176 t, respectively. One of the results showed that the natural period became longer and shorter by 10 to 30 % when the suspended load was in the air and half in the water, respectively (**Fig. 6**). A numerical simulation confirmed the result and further showed that the differences in the natural period increased with the increase in the distance between the vessel and the suspended load.

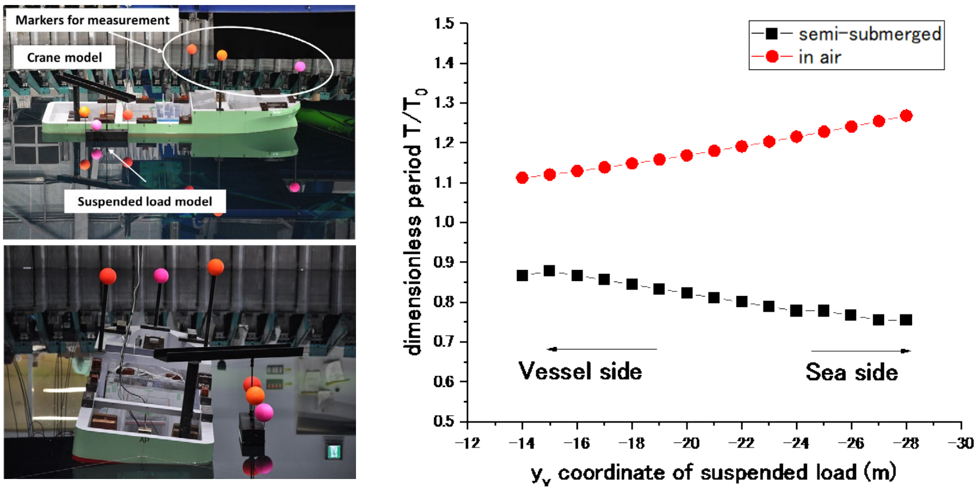


Fig. 6. Model experiments (left) and the variation of natural period with suspended loads in the air and half in the water (right). T_0 is the natural period without load

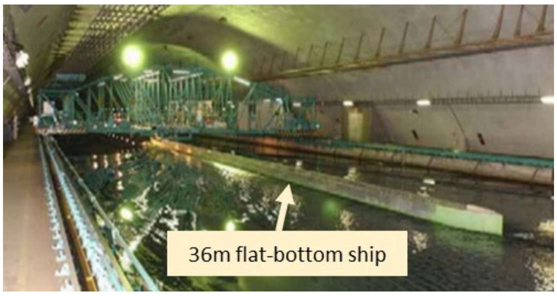
3.2 Zero-emission ship

The International Maritime Organization (IMO) declared in 2018 that the amount of the emission of CO_2 in international shipping is reduced by 50% by 2050 than the 2008 level. To meet this goal, several methods to reduce the amount of CO_2 emission are being examined. One of the methods is to use as fuel a mixture of petroleum fuel and ammonia, NH_3, or that of methane, CH_4, and hydrogen, H_2.

When NH_3 is used, one of the problems is the emission of nitrous oxide, N_2O, which has the greenhouse gas (GHG) effect about 300 times that for CO_2. MPAT experimentally showed that the double injection of light fuel oil, in which the oil is lightly injected before the main injection, drastically reduced the amount of N_2O. The reduction rate of N_2O reached 84% for a mixture of fuel containing 45% NH_3 and 55% light fuel oil by lower heating value. As a result, the reduction rate of GHG became 46%.

Adding H_2 into Liquified Natural Gas (LNG), of which about 90% is CH_4, reduced the amount of unburned CH_4, which has GHG effect 25 times that for CO_2. The unburned CH_4 was reduced more by controlling excess air ratio. To confirm the validity of those methods, MPAT conducted experiments by using city gas instead of LNG. The reduction rate of CH_4 was about 50% for a mixture of 20% H_2 and 80% city gas at a load factor of 25% and increased to about 80% by controlling the excess air ratio in addition. As a result, for a mixture of 60% H_2 and 40% city gas at a load factor of 25%, the reduction rate of GHG reached 70%. The emission of NOx, which is also a problem when LNG mixed with H_2 is used, was reduced by water injection.

Another method for the reduction of CO_2 emissions is to decrease the frictional resistance of a ship by injecting air bubbles from the bottom of the ship and make it flow more efficiently. Model experiments conducted in a 400 m towing tank showed that air bubbles repetitively injected with intervals reduced the frictional force by at most 5% than continuously injected bubbles (**Fig. 7**) and by at most 20% than no air bubbles.



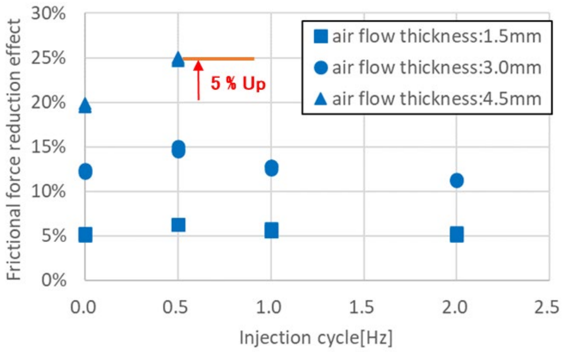


Fig. 7. Resistance test in a 400 m towing tank (left) and reduction effect of frictional force at a towing speed of 8m/s (right)

3.3 Blue Carbon

Blue Carbon is CO_2 stored in ocean and coastal ecosystems, which was firstly used in United Nations Environment Programme (UNEP) in 2009. Thus, Blue Carbon is relatively new research topic, and MPAT is one of the leading research institutes for the Blue Carbon research.

CO_2 is captured in particular in the shallow water region including seagrasses, mangroves, and salt marshes as well as seaweeds, tidal flats, and coral reefs. The amount of CO_2 taken by shallow water ecosystems across the globe was estimated based on the values listed in articles and reports. The estimated value was 1.07 billion t C/year (3.92 billion t CO_2/year) on the average (**Fig. 8**). Then, the value in Japan was estimated using more detailed parameters according to the Intergovernmental Panel on Climate Change (IPCC) guidelines. It is 1.32 million t CO_2/year on the average and 4.01 million t CO_2/year at most.

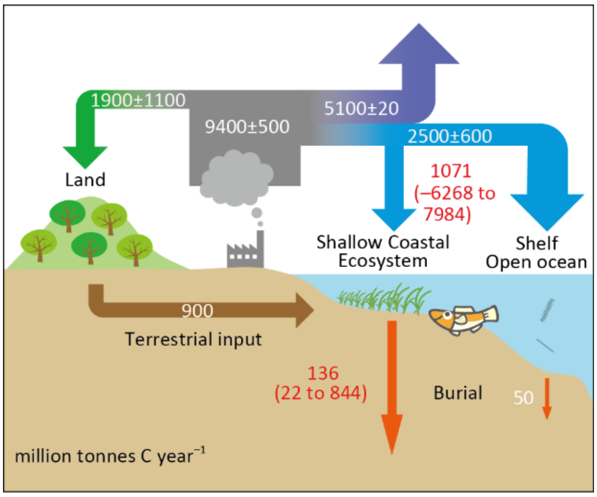


Fig. 8. Global carbon cycling (from Kuwae and Crooks 2021)

In the CO_2 sequestration in the shallow region, the storage of organic carbon, C_{org}, is one of the vital processes. The C_{org} accumulation rate and the controlling factors for 8,000 years in two lagoons in Japan were investigated using isotopic and elemental signatures. The results showed that the C_{org} accumulation rate was larger in salt marshes than in seagrasses and that it increased as the sediment accumulation rate increased during the period of the relative sea level rise (**Fig. 9**).

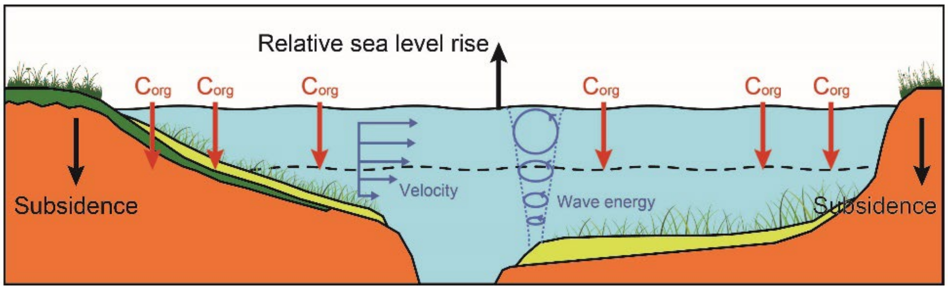


Fig. 9. C_{org} accumulation rates increased in response to relative sea-level rise (from Watanabe et al. 2019)

3.4 Fixed Flight-Path Angle (Fixed-FPA) Descent for efficient aircraft arrival operations
Aircraft generally follows a descent profile (altitude and speed) calculated by the onboard Flight Management System which is adjusted according to Air Traffic Control (ATC) instructions for safe separation with surrounding traffic. Continuous Descent Operation (CDO) is a potential aircraft operating technique for reducing CO_2 emissions which enables a descent profile optimized to the operating capability of the aircraft as a continuously descending path with idle-thrust. However, CDO can disperse significantly depending on the aircraft making trajectory prediction a daunting challenge for ATC. This leads to relatively long intervals between aircraft to maintain safe separation. As a result, CDO is not preferrable during high-traffic conditions. As a solution, MPAT proposed fixed flight-path angle (Fixed-FPA) descent in which an aircraft continuously descends at a fixed flight-path angle with near-idle thrust. **Fig. 10** depicts the proposed concept design. Fixed-FPA descent consumes slightly more fuel compared to CDO but significantly increases the trajectory prediction accuracy which is vital for reducing low-efficient level-off / holding procedures at high-traffic environment. Various fast-time and full-flight simulations were conducted at the Kansai International Airport for procedure validation.

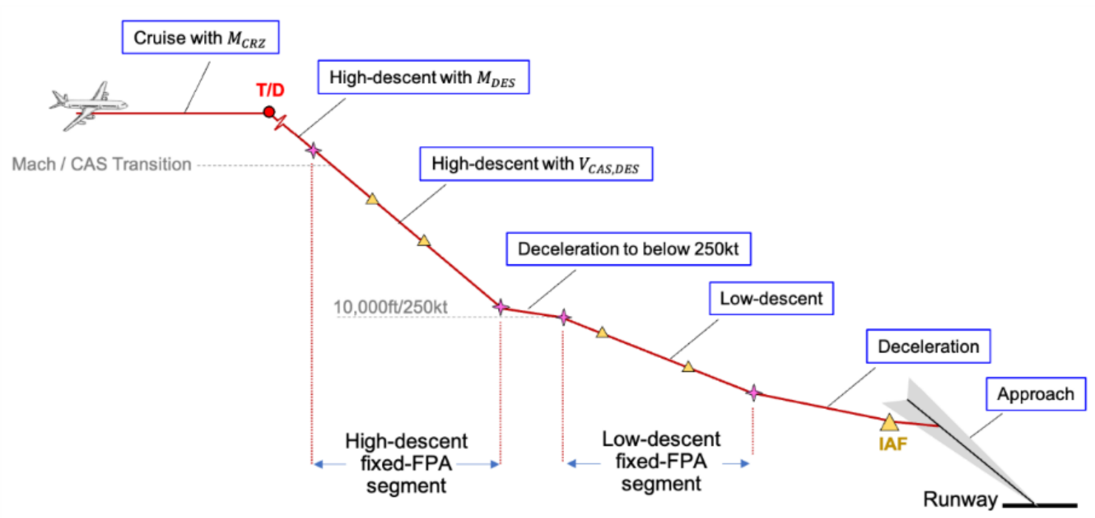


Fig. 10. Fixed-FPA Descent concept design

4. Future development

In this article, I introduced some of our research projects towards carbon neutrality. Our institute, MPAT, has scientists and engineers in a relatively wide range of fields in transportation engineering such as shipbuilding, ocean development, marine and coastal environment, ports and airports, and air traffic management. To contribute to the achievement of the government's challenging target in 2050, discussion and interaction across various research groups in our institute are important. However, not only those actions but also cooperation and collaboration with industry, universities and other research institutes are crucial. By promoting such joint activities, we will expand and develop our research for the future carbon-free world.

References

[1] Kuroiwa, T. and Chen, X.: Feasible study on spar type floater for 15MW wind turbine, The 43rd Wind Energy Symposium, Japan Wind Energy Association, 2021.
[2] Nakamura, K., Matsumura, S. and Mizutani, T.: Particle-to-surface frictional contact algorithm for material point method using weighted least squares. Computers and Geotechnics, 134, 104069, 2021.
[3] Kuwae, T. and Crooks, S.: Linking climate change mitigation and adaptation through coastal green-gray infrastructure: a perspective. Coastal Engineering Journal, 63, 188-199, 2021. https://www.tandfonline.com/doi/full/10.1080/21664250.2021.1935581.
[4] Watanabe, K., Seike, K., Kajihara, R., Montani, S. and Kuwae, T.: Relative sea-level change regulates organic carbon accumulation in coastal habitats. Global Change Biology, 25(3), 1063–1077, 2019. https://doi.org/10.1111/gcb.14558.

◆ A brief CV of Dr. Yoshiaki Kuriyama

Yoshiaki Kuriyama is the President of the National Institute of Maritime, Port and Aviation Technology (MPAT) in Japan. He graduated from the Department of Civil Engineering, Tokyo Institute of Technology, and joined the Port and Harbour Research Institute (PHRI), Ministry of Transport, in 1983. Since then, he has been conducting the research work on waves, currents, and sediment transport in the nearshore zone. He was appointed as the Director General of the Port and Airport Research Institute (PARI), the successor of PHRI, in 2016 and as the President of MPAT in 2020.