PARI

Annual Report 2020

Port and Airport Research Institute Annual Report 2020

Creating Technologies That Contribute to the World

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In April 2016, three research centers – the National Maritime Research Institute (NMRI), the Port and Airport Research Institute (PARI), and the Electronic Navigation Research Institute (ENRI) – were merged to form a new national research and development agency, the National Institute of Maritime, Port and Aviation Technology (MPAT). Now a part of MPAT, all of us working at PARI remain committed to maintaining our heritage as a research institute that has contributed to surveys, research, and technological advancement in port and airport development, and to continuing to serve our designated roles. After our predecessor organization, the Port and Harbour Research Institute, was created as a division of the Ministry of Transport in 1962, the organization provided technical support on numerous port, harbor, and airport projects, including the development of Kashima Port and the construction of Haneda International Airport and Kansai International Airport, and also conducted research activities that produced world-renowned results. Looking ahead, PARI will effectively collaborate with the two other research institutes it has been integrated with, in addition to continuing to work closely with the National Institute for Land and Infrastructure Management (NILIM) at the Ministry of Land, Infrastructure, Transport and Tourism (MLIT), in order to develop and extend the collaboration and consolidation in multidisciplinary research among the MPAT member institutes. By leveraging the synergistic effects of the consolidation of member institutes, PARI will strive to achieve maximum results in its research and development.

This annual report summarizes PARI's track record in FY 2019, the fourth year of the first mid-term plan (from FY 2016 through FY 2022). In this plan, PARI is focusing on the following four research and development challenges: Coastal Disaster Mitigation and Restoration, Formation of Infrastructure for Vigorous Economy and Society, Preservation of Marine Interests and Utilization of Oceans, and Creation and Utilization of Coastal Environment.

For Coastal Disaster Mitigation and Restoration, we have been conducting research on topics such as estimating the damage caused by maximum-level earthquakes, storm surges and high waves, analyzing tsunami-induced scouring, and studying structural stability.

For the Formation of Infrastructure for a Vigorous Economy and Society, we have been conducting research projects involving evaluation of the long-term durability of infrastructures, development of inspection and diagnostic technology, improvement of existing facilities, development of facility upgrading technology, and examination of methods to improve cargo-handling efficiency at container terminals, etc.

For the Preservation of Marine Interests and Utilization of Oceans, we have been engaged in projects for the preservation of ports and harbors on remote islands and other territories of Japan in general, development of acoustic video cameras that serve as basic technology enabling i-Construction, and development of reasonable design techniques to create offshore wind power plants, etc.

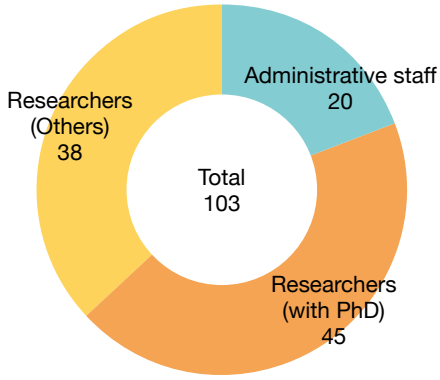
For the Creation and Utilization of Coastal Environments, our research has focused on developing a novel coastal ecosystem model that can quantify the amounts of blue carbon (i.e., mitigating effect) existing in various coastal areas, and also enable ocean-wave attenuation predictor models (i.e., adaptation effect) while considering the effects on the ecosystem.

In executing these research activities, PARI will continuously strive to live up to its two major mottos, which are to conduct research at the world's highest level and to make sure that the results of its research are useful in actual projects. In addition, PARI will promote government-led strategic international activities, including contributing to the expansion of infrastructures overseas and providing technical assistance to other countries. Furthermore, in order to tackle various technological challenges that encompass different research fields, PARI has internally set up five mission-driven centers (the International Research Center for Coastal Disasters, the Life Cycle Management Research Center, the Ocean Infrastructure and Offshore Wind Energy Research Center, the Productivity Improvement Research Center, and the Innovation Promotion Center), through which we intend to continuously enhance our collaboration with private-sector companies as well as with the Regional Development Bureau and other divisions of MLIT that manage project sites where our technologies are implemented. In view of the increasing number of natural disasters such as earthquakes, storm surges and high waves in recent years, there is an urgent need to improve the resilience of our national land. While recognizing the unique position of PARI as a research institute responsible for conducting practical R&D activities that can be utilized in actual on-site operations under the demanding natural conditions specific to Japan, we intend to continuously leverage all knowledge, human resources, and other assets that are available at PARI in order to provide disaster-prevention education to the public, respond to emergencies during earthquakes, tsunami, and other disasters, and assist post-disaster recovery efforts in a reliable manner.

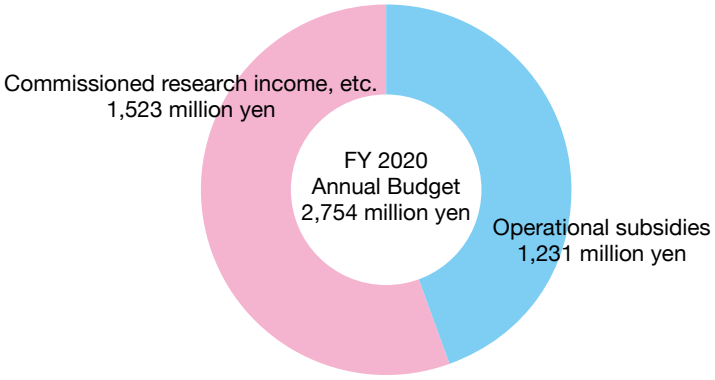
We would greatly appreciate your continued support.

CONTENTS

Administrative Staff and Researchers, and Budget

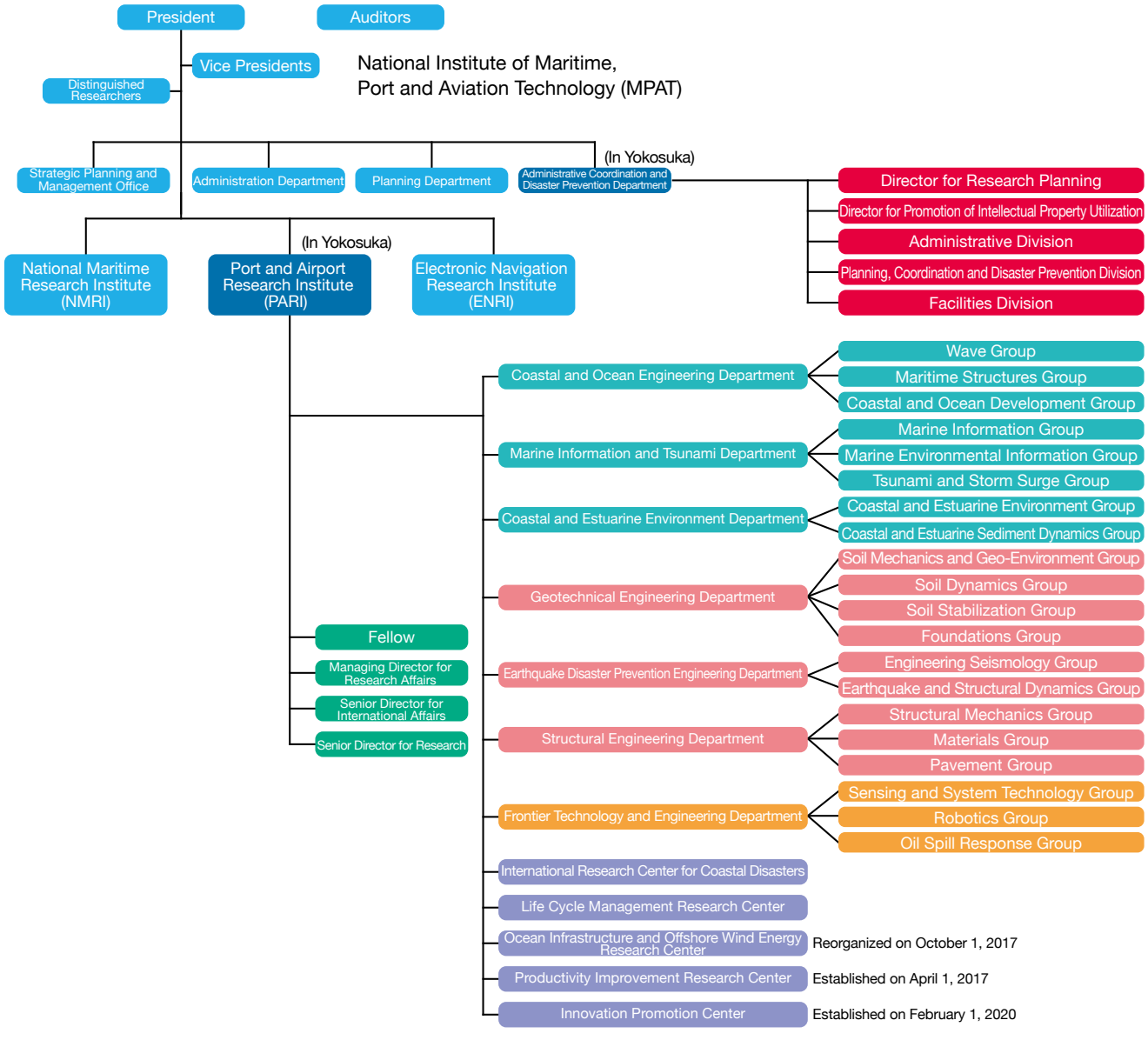


As of April 1, 2020 (In Yokosuka)



* The graph above shows the budget for technical fields related to ports, waterways, coasts, and airports.

Organizational Structure



As of April 1, 2020

Mid- and Long-Term Objectives (FY 2016 to FY 2022)

The Minister of Land, Infrastructure, Transport and Tourism (MLIT) sets mid- and long-term business goals for the National Research and Development Agency, National Institute of Maritime, Port and Aviation Technology to achieve. These goals stipulate our operations as follows.

Basic Policies for Structural Reform of Independent Administrative Institutions were decided in a Cabinet decision on December 24, 2013 (hereafter called "Basic Policies for Reform"). Based on these policies, the National Maritime Research Institute (NMRI), Port and Airport Research Institute (PARI), and Electronic Navigation Research Institute (ENRI), which were National Research and Development Agencies operated under the jurisdiction of the MLIT, were integrated into the National Institute of Maritime, Port and Aviation Technology (hereafter called "MPAT") to implement the policies.

Article 2, paragraph 1 of the Act on General Rules stipulates as follows: some clerical tasks and business require sound implementation from the viewpoint of general welfare including stabilization of people's life and socioeconomy, but at the same time do not require government-led implementation. Some of these clerical tasks and businesses face the risk of neglect when their operation is entrusted to private entities, so MPAT was established to effectively and efficiently conduct their operation.

In consideration of the previous roles of each institute, MPAT is required to continue to make full use of its accumulated wealth of knowledge and stature, and to proceed with research and development according to the Basic Policies for Reform. In addition, MPAT will constantly review research contents and select research areas to address changes in the social environment. At the same time, MPAT will more actively engage in research and development activities to solve policy challenges in each field, such as conducting research in emerging fields.

MPAT has promoted research and development in each field, cultivated technological seeds, and accumulated specialized knowledge. Thanks to MPAT's legacy, such multidisciplinary research became viable. In consideration of this background, MPAT will efficiently and effectively implement multidisciplinary research including "Promoting the protection of maritime interests and the utilization and application of marine-resource/marine-renewable-energy development and other projects". Through such implementation, MPAT will help put national policies into practice.

Furthermore, MPAT considers that it is important to return the benefits achieved through research and development to society, as well as to cooperate with external institutes and to widely disseminate research results. In addition, MPAT is committed to strategically implementing international activities as follows: active participation in projects to formulate international criteria and standards; international promotion of Japanese technologies and systems through international cooperation; and other activities.

As outlined above, MPAT's missions are based on the MLIT's Basic Plan for putting MLIT-recommended policies into practice. Today, Japan faces various important challenges. By realizing these policies, we can solve such challenges.

Mid- and Long-Term Plans (FY 2016 to FY 2022)

The MLIT sets mid- and long-term goals. In response to such goals, MPAT sets mid- and long-term plans to achieve the goals. Among such plans, important points in maximizing research and development results and improving the quality of other projects are outlined below.

1. Promotion of multidisciplinary research and other activities

MPAT will efficiently and effectively implement multidisciplinary research spanning research fields of the three pre-integration institutions to contribute to putting the following policies into practice: promotion of ocean utilization, enforcement of international industrial competitiveness, and other policies.

2. Research and development of technologies associated with ports, water ways, coasts, and airports and other activities

MPAT will focus on the research and development challenges detailed in the following pages, to devise the following MLIT-recommended initiatives: disaster-prevention and disaster-reduction countermeasures for port and airport facilities; countermeasures for facility obsolescence of existing structures; and initiatives to create maritime-development hubs.

Among basic research, MPAT also actively engages in research to understand the mechanisms of ocean waves and beach transformation and principles and phenomena regarding the dynamic behavior of the ground and structures.

MPAT also uses its foresight and flexibility to accurately address emerging research which might lead to new research results.

3. Returning benefits from research and development results to society

MPAT will try to resolve technological policy challenges, to address disasters and accidents, to enforce bridging functions, to promote and utilize intellectual property right, and to enhance the transmission of information and publication.

4. Promotion of strategic international activities

MPAT will contribute to international standardization and cooperate with overseas institutions.

MPAT Operation Management

MPAT will focus on rapid decision-making to engage in strategic institutional operations.

MPAT will also hold the following meetings for multi-faceted investigation of various operational agendas from a broad perspective:

1. Management strategy meetings: In-house meetings for making decisions on important issues related to the core principles of MPAT management
2. Board of Directors meetings: Weekly meetings involving all executives and division managers as well as the three directors of the Administrative, Coordination and Disaster Prevention Department
3. Board of Councilors meetings: Meetings to gather insights from independent experts who have broad and deep knowledge
4. External Evaluation Board: An external body in which third parties objectively and technically evaluate MPAT's research

Structure of Research Themes in FY 2019

Research Field	Research Theme	Research Subtheme	Type of Research		Item on the Research Agenda (☆indicates special research*)
1. Coastal Disaster Mitigation and Restoration	1A Research on Mitigation of and Restoration from Earthquake Disasters	① Research on strong ground motions and damage predictions in the case of the greatest earthquakes	Fundamental Research		Strong motion earthquake observation in port and airport area (2A②)
			Fundamental Research		Investigation of earthquake disaster (2A②)
			Fundamental Research		Development of estimation method for near-fault strong ground motions
			Fundamental Research		Study on the evaluation and analysis of liquefied ground behavior and effective countermeasures under sequenced earthquake motions
		② Research on damage-reduction techniques against the greatest earthquakes	Applied Research	☆	Development of seismic performance evaluation method for offshore wind turbines and coastal structures against the largest earthquake motions
			Applied Research		Development of countermeasures for early exhibition of seismic performance of coastal facilities
		③ Research on the interaction of earthquakes, tsunamis, and high waves with ground dynamics	Fundamental Research		Study from geotechnical view-point on stability evaluation method of coastal structure subjected to high waves (1C②)
			Applied Research	☆	Stability evaluation of offshore structures against washout, cavity formation, etc. and development of countermeasure techniques (1C②)
	1B Research on Mitigation and Restoration of Tsunami Disasters	① Research on ICT-based decision support systems	Development Research		Development of a 3-dimensional simulation model for drift behavior and its application to a 2-dimensional simulation model
			Development Research		Development of multi-observation based tsunami forecasting method
		② Research on the development of tsunami-resistant ports	Fundamental Research		Development of the estimation method for local scour around coastal structures due to tsunami
			Development Research		Application of the particle method to the large deformation of port structures due to tsunami
	1C Research on Mitigation and Restoration of Storm Surge and Wave Disasters	① Research on storm surge, wave and maximum damage estimation	Fundamental Research		Elucidation of oceanographic phenomena based on central processing and analysis of observation data
			Applied Research		A study of seasonal and regional statistics on swell observed in Japanese coast
			Development Research		Development of a harbor tranquility analysis method for local wind waves and ship waves in a harbor
			Applied Research		Estimation of wave transformation around damaged structures to evaluate remaining performance for sheltering
			Applied Research		Assessment of possible maximum storm surge hazard by using storm-surge-wave coupled model
		② Research on the technology to reduce maximum storm surge and wave disasters	Applied Research	☆	Study on wave forces on the structural members of protective facilities under storm surges, high waves, and tsunami (1B②)
2. Formation of Infrastructure for Vigorous Economy and Society	2A Research on Enhancement of Port and Airport Performance for Industrial Competitiveness	① Research and development for enhancing the operations of ports, harbors, and airports	Applied Research		Proposal of evaluation method to estimate the productivity of the container terminal system introduced AI and ICT technology or other method
		② Development of technology to assist efficient and effective development of ports, harbors, and airports			(All research items marked "2A②" in this Table)
	2B Research on Life Cycle Management of Infrastructures	① Research on technologies for prolonging the life of infrastructure	Fundamental Research		Evaluation of longterm durability of concrete, steel and various materials based on exposure test
			Fundamental Research		Evaluation of applicability of sustainable materials in the marine environment
			Fundamental Research		Development of the performance evaluation method in protective coating for marine structures
			Fundamental Research		Evaluation of the durability of various materials under severe environments
			Applied Research		Study of the effects of steel mesh in concrete pavement used at airports from the design and implementation perspectives (2A②)
			Applied Research	☆	Systematization of repair and strengthening of marine concrete structures
		② Research on systems for inspecting and diagnosing infrastructure	Applied Research		Study on application of inspection and diagnosis systems for improvement of performance evaluation of marine structures
			Development Research		Development of adaptive technique for inspection vehicle to disturbance in operation (2A①)
		③ Research on maintenance and management systems for infrastructure	Applied Research		Study on maintenance planning of port facilities in term of LCC optimization
	2C Research on Effective Use of Existing Infrastructure Facilities	① Research on techniques to improve or renew existing facilities	Applied Research		Development of quality evaluation method for ground improvement using geophysical exploration (2A②)
			Fundamental Research		Study on process leading to rupture of pier structure for high definition of performance regulation
		② Research on effective use and techniques of treating construction byproducts	Fundamental Research	☆	Enhancement of accuracy of method for evaluating mechanical properties of composite geomaterials based on microstructural feature
			Applied Research		Development of technique increasing capacity of disposal site for dredged soil
		③ Research on management and utilization of waste disposal sites at sea			-
3. Preservation of Marine Interests and Utilization of Oceans	3A Research on Development and Utilization of Oceans	① Research on port construction and management in remote islands	Development Research		Study on technique of wave sheltering for isolated coral reef area
			Development Research		Technological development on advanced ship mooring system in port
			Fundamental Research	☆	Development of analytical methods for the topographic dynamics of carbonate islands
		② Research on infrastructure technology for utilization and development of oceans	Development Research		Development of next-generation acoustic imaging system (2A①)
			Development Research		Research on adaptation of the machine guidance for an underwater excavator (2A①)
			Applied Research		Study on floating breakwater equipped with wave power generation device
			Applied Research		Research on the estimation method of wave force acting on offshore wind power facilities
			Fundamental Research	☆	Elucidation of the horizontal resistance characteristics of pile foundations for offshore wind power plants under various fluctuating loads (2C①)
4. Creation and Utilization of Coastal Environment	4A Research on Enhancement and Utilization of Coastal Ecology	① Research on coastal-ecosystem utilization	Fundamental Research	☆	Validation of the newly developed global dynamic model for the projection of atmospheric CO_2 uptake rate and inundation control in shallow coastal ecosystems
			Applied Research		Coastal geotechnical/geomorphological design for disaster mitigation and ecological environment
		② Research on the water-environment simulation and analysis in inner-bay	Fundamental Research	☆	Cross-sectional observation and analysis of atmospheric and oceanographic issues at bay mouths
			Fundamental Research		Analytical study of macro-organisms dynamics on a coastal ecosystem simulation
			Fundamental Research		Development of the methods for increasing ecosystem functions in eelgrass meadow
			Applied Research		Numerical analysis of coastal current by numerical simulation and data assimilation
		③ Research on countermeasure technologies against sea oil spill	Development Research		Development of oil spill response technology for next generation
	4B Research on Coastal and Estuarine Processes	① Research on coastal protection and maintenance of waterways and mooring basins	Fundamental Research		Developing future projection model of coastal change in the context of climate change
			Fundamental Research		Observation of coastal phenomena at HORS and development of numerical simulation of topography change for port and surrounding beaches
			Fundamental Research		Study on sediment transport in estuary and deposition process in navigation channel
			Fundamental Research		Study on applicability of airborne laser bathymetry for topographic monitoring in coastal zone of sea shore

* Special research involves high-priority research topics on which PARI must conduct studies intensively. PARI allocates significant human resources and funding to these projects, and also arranges cross-functional research systems extending beyond the basic organizational structure within PARI as needed, in order to accelerate research.

1A Research on Mitigation of and Restoration from Earthquake Disasters

Background and Objectives

- In the event of large-scale disasters including Nankai megathrust earthquakes and earthquakes in the greater Tokyo area, it is required to secure necessary trunk line cargo transportation soon after an earthquake and to quickly secure the requisite minimum transportation of key emergency supplies for recovery and reconstruction. In addition, the interaction of earthquakes, tsunamis, and high waves with the ground might cause coastal disasters, so it is necessary to reduce such risks.
- Therefore, the themes of this research cover research and development which simultaneously achieves the two goals of improving earthquake resistance and reducing construction costs. These two goals can be achieved through diagnosis and performance verification of earthquake-resistance of facilities which address the properties of long-period and long-duration earthquake ground motion, which is expected to occur during a subduction-zone megathrust earthquake, as well as the properties of earthquake ground motion caused by local ground characteristics. Research and development are being conducted mainly on methods for investigating and diagnosing earthquake resistance as well as construction methods that improve the resistance of existing facilities with limited design life that were erected during the era of rapid economic growth without disturbing their use.

Research Topics

Research and development comprises the following three subthemes:

i) Research on strong ground motions and damage predictions in the case of the greatest earthquakes

Subduction-zone megathrust earthquakes may cause the greatest and long-duration earthquake motions, so we will develop techniques for predicting such motions. Also, we will develop techniques for predicting liquefaction and structural damage caused by such motions.

ii) Research on damage-reduction techniques against the greatest earthquakes

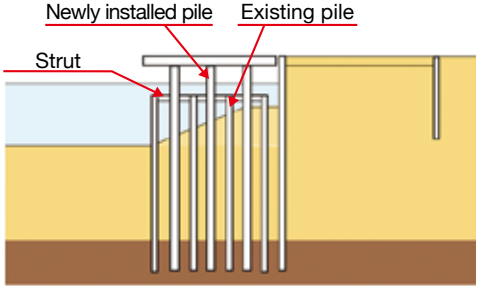
We will suggest the most effective countermeasures under given limitations to effectively promote seismic strengthening of existing structures. In doing so, we will actively utilize damage reduction and strengthening techniques that use novel materials, structures, and construction methods. Especially, as measures for improving earthquake resistance of industrial complexes, we will consider maintaining the functions while reducing costs for overall plants, and then develop investigation, diagnosis and countermeasure techniques which minimize usage limitations of plants. In addition, we will develop methods to rapidly evaluate damage levels on site immediately after a disaster as well as emergency restoration techniques.

iii) Research on the interaction of earthquakes, tsunamis, and high waves with ground dynamics

We will proceed with research on the following interaction problems of earthquakes and ocean waves with the ground: stability evaluation against seabed liquefaction, washout, cavity formation and collapse under earthquakes or under ocean waves; a mechanism in which a breakwater foundation loses its bearing capacity in the presence of tsunami; and other interaction problems. Also, we will use numerical simulation models, model experiments (on a centrifuge and a large-scale fluid tank), and other methods to investigate earthquake-induced submarine landslides, the resulting tsunamis, ground dynamics including deformation and failure under the influence of tsunami and high waves, as well as their countermeasures.

Activities in FY 2019

- We obtained 1,900 strong motion earthquake records during the period between January to December 2019. Of those data, the motion recorded at the Port of Soma showed the maximum amplitude with a maximum acceleration of 159 Gal, which was caused by the earthquake (M6.4) that occurred off the coast of Fukushima Prefecture on August 4. As progressive efforts had been made to implement a system that would automatically distribute by email preliminary seismic motion data as they were acquired, preliminary data on the earthquake were transmitted roughly 10 minutes after it occurred. In addition, we collaborated with the MLIT and the Regional Development Bureaus to improve the system, etc. concurrently with the upgrading of strong-motion seismometers.
- Concerning the RTK-GNSS-based system called “Berth Surveyor” that was developed in the previous year to swiftly determine the safety of mooring facilities following major earthquakes, we improved its display function and also held discussions with the MLIT and the Regional Development Bureaus on ways for using the system. Information on the system was disseminated to related parties, and its trial implementation was done on site.
- We conducted fundamental researches on the issue of the discretization of fault planes, etc., with a view to developing a comprehensive strong-motion prediction method that can not only take into consideration the strong ground motions due to the rupture of asperities in the deeper parts of the fault but can also take into account the effects of shallower slip which was widely recognized after the occurrence of the Kumamoto earthquake.
- We evaluated and analyzed the liquefaction behavior of grounds subject to successive earthquake motions or had fine content, and suggested a technique for suppressing the amount of internal ground flow and boiling that would occur with the propagation of liquefied zones.
- Concerning offshore wind turbines, we started developing an analytical code for elucidating their behavior when subjected to various external forces including seismic motions, wind, etc. and developing a reliable method for evaluating their seismic performance.
- In order to develop a structure that can achieve desired seismic performance at an early stage after a major earthquake, we examined a new method for retrofitting existing pile-supported mooring facilities by installing struts and new piles. In addition, we conducted shake table tests using scale models and analyzed the test results to elucidate the basic characteristics of their behavior during earthquakes and how their seismic performance could be improved.
- We conducted stability evaluations and analyses of washout and cavity formation caused by various dynamic external forces resulting from earthquakes, waves, and currents, elucidated their characteristics and mechanisms, and evaluated novel countermeasure technologies that could effectively suppress such washout and cavity formation.
- We developed a centrifuge model-based experimental method for studying the rupturing behavior of grounds caused by waves and currents, and examined a method for evaluating the stability of coastal structures against high waves from a geotechnological perspective.



A new method for improving the seismic performance of an existing pile-supported mooring facility by installing struts and new piles

1B Research on Mitigation and Restoration of Tsunami Disasters

Background and Objectives

- Since the Great East Japan Earthquake in 2011, we have studied stable structures against tsunami overflows and developed a numerical simulation model to predict the drifting of debris generated by the destruction of buildings. However, complex behaviors of tsunami run-up on land and the resulting damages are not fully understood and modeled yet. In addition, regarding a technique for real-time inundation forecast, which is expected to be utilized for evacuation and other purposes, only data from GPS-mounted wave buoys is used; other valuable data is not fully utilized yet.
- Therefore, we are aimed for changing disaster prevention and reduction countermeasures into a pre-disaster stage from post-disaster one, and will conduct research to establish resilient coastal zones which can withstand the most severe tsunamis, i.e., to protect lives against the most severe tsunami, to avoid catastrophic socioeconomic damages, and to enable early recovery and reconstruction.

Research Topics

Research and development comprise the following two sub-themes:

i) Research on ICT-based decision support systems

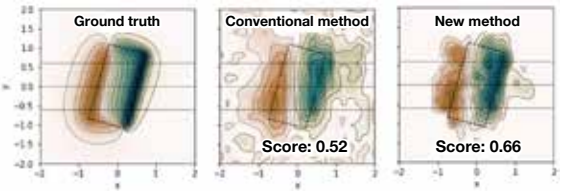
We have previously developed a system for rapid forecasting of tsunami inundation, which utilizes offshore-tsunami waveforms observed by GPS-mounted wave buoys. For highly reliable tsunami prediction, we will additionally utilize ground deformation data obtained by on-land GPS base stations and remote-sensing information including ocean HF radars, and will refine the system. To ensure the safety of evacuation sites, it is necessary to assess not only tsunami-induced inundation depth but also the tsunami velocity and floating objects to determine the resistance of structures and even to assess fires, which are associated with floating objects. So, we establish an integrated simulation system which can assess these risks.

ii) Research on the development of tsunami-resistant ports

We will clarify the structures of violent flows, scours around structures induced by large tsunami-overflows, and the influence of drifting objects including ships and vessels on the damages. Then, we will develop a method of designing tsunami-resistant breakwaters and other facilities as well as a method of planning tsunami-resistant ports. We will also develop a 3-D multiphysics numeric calculation model that incorporates novel calculation methods such as particle methods and that can perform computations while considering both fluids and solids as one, to be used as a new design and planning tool, in addition to the numeric calculation models that were previously developed. Moreover, we will conduct a large-scale model experiment to validate the robustness and accuracy of the numerical model, and will understand complex tsunami phenomena in port cities.

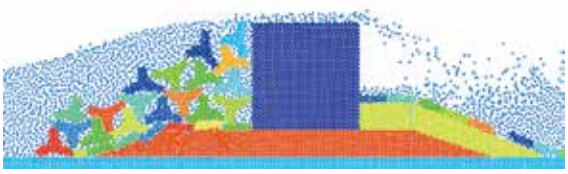
Activities in FY 2019

- As for the development of a 3-D simulation model for drift behavior and its application to a 2-D simulation model, we conducted the experiments on drift objects in a coastal area including a port and studied the methods of coupling the fluid model and drift object model that are integrated in the 3-D simulation model. In these experiments, we acquired 3-D data using acceleration sensors embedded in drift objects of various shapes and analyzed plane behavior of the drift objects by image analysis.
- Aiming to build a multi-observation based tsunami forecasting method, we developed a new tsunami source inversion method that utilizes data-driven bases created by time-reversal imaging, which improved the accuracy of the tsunami source estimation by 14%. In addition, we succeeded in developing a reciprocal-theorem-based technique that reduced the cost of calculating Green's functions, which is necessary for the tsunami source estimation, to approximately 1/100. These new technological inventions allow us to perform the tsunami source analyses with ultrahigh resolution, which are expected to improve the accuracy of tsunami waveform prediction.

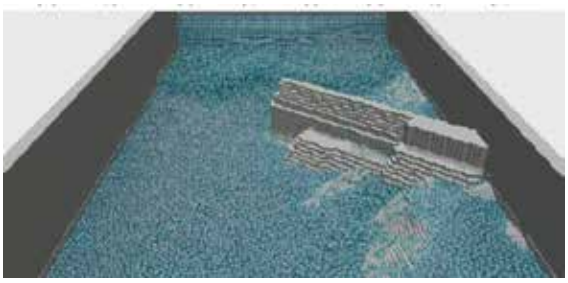


Comparison of accuracy in rectangular fault tsunami source estimation between the conventional and new methods

- Regarding the development of a method for estimating local scour that a tsunami causes around structures, we conducted large-scale hydraulic experiments and performed numerical calculations on local scour that occurs near the breakwater head, and identified the characteristics of the large eddy that occurs around the head. In addition, we conducted experiments on the scour that occurs behind the breakwater due to tsunami overflow and clarified that the rubble mound suppresses overflow-induced scour.
- Concerning the application of particle methods to tsunami-induced large deformation of port structures, we developed the multi-physics model based on the Discrete Element Method and a porous model to simulate the behavior of various rigid objects, e.g. mounds, blocks, caissons. In addition, we have developed a novel wave-generation model that considers the incident wave height as the only parameter and built a framework in which the model can be easily connected to 2-D planar simulation models.



(2-D simulation)



(3-D simulation)

Analysis of flow around breakwater in a numerical wave tank utilizing the particle method

1C Research on Mitigation and Restoration of Storm Surge and Wave Disasters

Background and Objectives

- Since Typhoon Vera struck in September 1959, there have been no devastating storm surge and wave disasters in Japan. However, the U.S. suffered severe damages due to Hurricane Katrina in September 2005, and so did the Philippines due to Typhoon Haiyan in November 2013. In future, global warming might bring higher storm surges and waves than those we have expected in Japan.
- Therefore, this research is aimed for changing disaster prevention and mitigation measures into a pre-disaster stage from post-disaster one and focuses on how to mitigate damage by the maximum storm surge and wave conditions and how to rapidly recover and reconstruct after the damage has occurred. Therefore, we conduct research to encourage hard and soft measures. Specifically, we will develop a numerical model to estimate the maximum storm surge and wave and their damage and will also develop design methods to build robust structures.

Research Topics

Research and development comprises the following two subthemes:

i) Research on storm surge, wave and maximum damage estimation

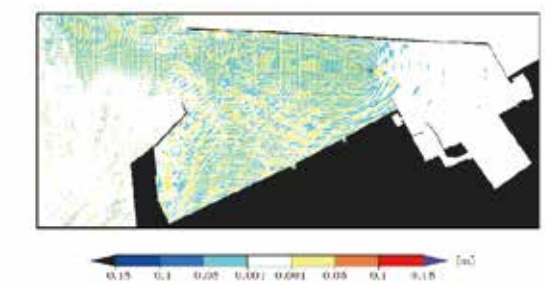
We will develop the following to determine the characteristics of the damage due to the maximum storm surge and wave: an accurate storm surge prediction model, which incorporates a weather model; and a new method based on a 3-D fluid model to simulate tidal levels and flows at the time of storm surge. Also, we will employ a high statistical analysis to estimate the effects of global warming on the maximum storm surge and wave and long-term variations in these statistics. In addition, we will establish a calculation technique to estimate the following wave transformations: the wave sheltering effects of breakwaters damaged through sliding, depression and others; and overtopping prevention effects of seawall having collapsed parapet, dispersed wave-dissipating blocks and other damages.

ii) Research on the technology to reduce maximum storm surge and wave disasters

We will elucidate structural stability under complex conditions in which unexpectedly high water level due to storm surge coincides with high waves. In addition, we will investigate methods of estimating the damage on structures due to storm surge and waves and countermeasure against such damages, and develop a method to design robust structures.

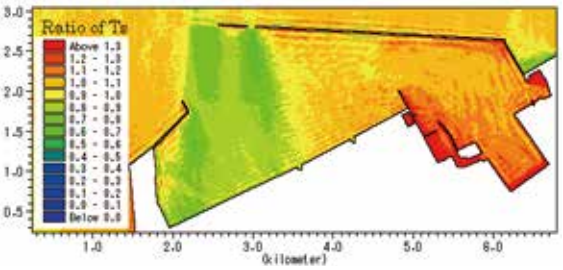
Activities in FY 2019

- Regarding the central processing and analysis of observational data on oceanographic phenomena, we organized the wave data observed through the Nationwide Ocean Wave Information Network for Ports and Harbours (NOWPHAS) in 2018 and compiled the annual wave observation report. Concerning the high waves caused by Typhoon Faxai that passed through Tokyo Bay from south to north, we analyzed the wave data acquired at the NOWPHAS station “Dainikaiho” and estimated them with a wave model.
- For studying the seasonal and regional characteristics of swells observed along the coast of Japan and the mechanism of the swell development, we organized data to better understand the wave directional spectrum with multi peaks and the occurrence characteristics of wind waves and swells. It led that wind waves appear more frequent on the coast facing the Sea of Japan where wind waves caused by the winter monsoon are prominent. Meanwhile, swells play a larger role on the coast of the Pacific Ocean where swells generated by summer typhoons reach the shore. We also quantitatively confirmed that wave directional spectrum with multi peaks appeared more frequently on the Pacific coast than on the Sea of Japan coast.
- Regarding the development of a harbor tranquility analysis method for local wind waves and ship waves, we suggested a novel harbor tranquility analysis method that considers ship waves, and quantitatively compared the cargo-handling efficiency between the conventional and presented methods. In addition, we conducted an experiment using a wind-wave flume to study the process of wave development under strong wind in a port, and discovered that the variation of water-surface friction velocity with wind velocity might depend on the initial state of the water surface.



Calculation of generation and propagation of ship wave from a sailing freight vessel (5,000 WT) in a port

- For the evaluation of wave transformation and propagation characteristics around damaged structures to consider remaining performance for sheltering, we studied planar harbor waves behind submerged breakwater to verify the accuracy of the NOWT-PARI Boussinesq model. In addition, we performed calculation of wave transformation on model ports to study the wave-controlling performance of the breakwater partially submerged by disasters and newly constructed submerged breakwaters, and quantitatively elucidated the effects of the breakwaters on harbor tranquility.



Shortening of swell wave period caused by partially submerged breakwater (compared to 12s)

- To assess the possible maximum storm surge hazard using a storm surge and wave coupled model, we first examined the reproducibility of storm surges along major coastal areas of Japan using the ROMS ocean model, and then focused on a sample port to estimate the storm surges and the associated coastal inundation using the ROMS-SWAN coupled model considering wave setup. In addition, we applied Emanuel’s MPI theory to calculate the maximum intensity to which typhoons could develop and evaluated a method for defining the worst class typhoon.
- Regarding the study on wave forces acting on the structural members of protective facilities under storm surges, high waves, and tsunamis, we conducted a hydraulic experiment to elucidate the wave force acting on seawalls having complicated structural cross sections which were damaged by Typhoon Faxai. In addition, we evaluated methods for estimating the maximum and time-series wave forces by applying ANN to the experimental data. We also verified the efficacy of a work method to prevent the detachment of geotextile sheets installed on backfill stones of seawalls by waves in a large-scale experiment.

2A Research on Enhancement of Port and Airport Performance for Industrial Competitiveness

Background and Objectives

- As Japan's population keeps declining, with the elderly comprising an ever-growing part of its society, and as many infrastructures built in the past continue to deteriorate, technological solutions are needed in order to achieve the following goals: Improve the global competitiveness of the industries in Japan, which are the main source of the country's vitality; identify means of maintaining the functions of the country's ports, harbors, and airports that are essential for sustaining people's living; and maintain, upgrade, and repair the aging infrastructures with limited financial and human resources efficiently and effectively while also trying to extend their lifespans.
- Toward the aforementioned goals, PARI has been committed to R&D, etc. for enhancing the functions of ports, harbors, and airports. As for the related subthemes that contribute to raising the country's competitive edge on a global scale such as adoption of policies on internationally strategic ports and enhancement of metropolitan airport functions (improvement of Haneda Airport), etc., we have been conducting R&D activities in a comprehensive manner throughout PARI.
- Concerning this particular research theme, we have been developing certain technology that will expand Japan's global competitive advantage, including implementation of ICT, AI, and other information technology at container terminals, and automation of cargo-handling services.

  As for PARI's activities to create technology that enables efficient and effective development of port and airport facilities, reports are provided under other research themes. Such activities include formulation of work and inspection methods that are better tailored to port and airport facility operations and work coordination, construction of large-scale facilities for rapid functional improvement, improvement of the seismic performance of facilities, maintenance and management of facilities after they are built, and improvement of existing facilities.

Research Topics

R&D on technology that contributes to improving the capability and functions of ports and airports

i) Proposal of evaluation method to estimate the productivity of the container terminal system introduced AI and ICT technology or other method

We will create data models for assessing various facility arrangements at the 1,000-m extension container terminal on New Honmoku Pier at the Port of Yokohama and evaluating the effects of CONPAS, remote-control RTG, and on-dock depots, and suggest suitable functions to be implemented, how to utilize those functions, and arrange facilities based on quantitative evaluation using AutoMod simulations.

ii) Proposal of planning method for automated container terminal by quantitative numerical simulation

We will formulate and suggest quantitative-simulation-based planning technology applicable to container terminals using the quantitative simulations previously run on Tokyo Port, Yokohama Port, Nagoya Port, Osaka Port, Kobe Port, and Hakata Port, while referencing the automated terminal planning guidelines currently being drafted by PIANC for issuance in 2021.

iii) Proposal of new technology for container terminal operations

We will conduct R&D on operation support technology (damage inspection system) pertaining to the container damage inspection system, autonomous control of gantry cranes, remote control of RTG, adoption of AI, etc., which have been funded with PRISM, etc., and will also provide technical support to the government.

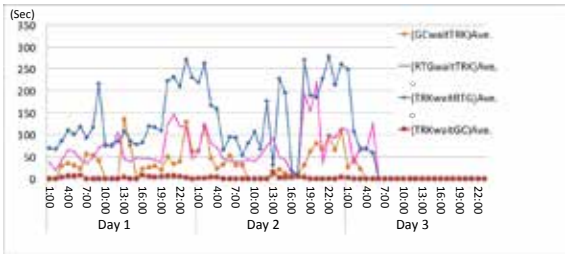
Activities in FY 2019

i) Proposal of evaluation method to estimate the productivity of the container terminal system introduced AI and ICT technology or other method

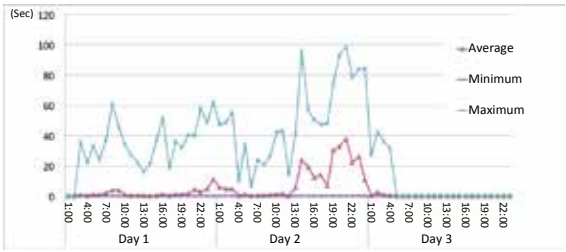
As for our specific activities that were conducted during FY 2019, we focused on New Honmoku Pier at the Port of Yokohama and ran AutoMod simulations on the gates, storage space, and overall pier operation while specifying numbers of GCs, RTGs, and gate lanes based on data from Minami Honmoku Pier MC-1 through 4 of Yokohama Port and assuming cargo-handling throughputs of 1,000,000 TEUs per year and 1,500,000 TEUs per year, which are more than the planned cargo-handling capacity. During this process, we created and evaluated data models related to the CONPAS reservation system, the prior clerk system, remote-control RTGs, and on-dock depots.

At a throughput of 1,500,000 TEUs per year, there would be many trucks waiting for their turns on the premises, so we determined that it would be insufficient to have the number of RTGs in proportion to how they are deployed at MC-3 and MC-4. Meanwhile, we also found that a long line of trucks waiting for their turns would still form even at a throughput of 1,000,000 TEUs per year. However, as there was waiting time for both RTG cranes and trucks, such congestion could be improved by devising a method that enables more suitable programming to optimize the matching between different cargo-handling machines. By simply adopting on-dock depots that can actively perform cargo-handling at night, these shortcomings could be improved significantly. As for the efficacy of CONPAS, we were able to verify it based on the fact that the amount of cargo passing through the gates had increased.

As for the remote-control RTGs, we found that having one person simultaneously handle operations of four RTG cranes during busy times would create idle time for the RTG cranes.



The graph indicates the idle time of different cargo-handling machines waiting for each other. It is apparent that RTG cranes and trucks (TRK) are waiting for each other. (Data is of a certain week where the required cargo capacity is 1,500,000 TEUs per year, assuming use of CONPAS, on-dock depots, and remote-control RTGs.)



One operator is assigned to four remote-control RTGs. Therefore, if more than one RTG must be operated simultaneously, idle time will occur while waiting for the operator to complete the operation of one crane at a time. The graph indicates such idle time.

As shown above, the on-premises cargo-handling capacity is clearly more critical than the throughput at the gates when large quantities of containers must be handled. Based on this finding, it is considered that use of an AI-powered terminal system that enables programming of efficient operations for the storage space and cargo-handling machines could improve the aforementioned issues.

2B Research on Life Cycle Management of Infrastructures

Background and Objectives

- The ports, airports and coastal infrastructures that have been in service for a long time are increasing, but financial resources and the number of engineers for facility maintenance are limited. As important port, airport, and coastal infrastructure functions should be maintained, the strategic maintenance, renewal, and other measures to maintain such functions are strongly required.
- Therefore, we are trying to establish methods for structure design and material selection which are excellent in terms of maintenance, and will develop techniques and technologies regarding various countermeasures for maintenance phase.

Research Topics

Research and development comprises the following three subthemes:

i) Research on technologies for prolonging the life of infrastructure

Regarding various construction materials in marine environments, we will conduct research on the following: evaluation of long-term durability, understanding of deterioration mechanisms, and investigation of the prevention effects of protective methods for steel structures. Especially, assuming that infrastructure is used overseas and on remote islands in Japan, we will investigate material characteristics for durability improvement under severe environments and under conditions in which low-quality material is used, and will investigate environmental-load reduction, durability improvement, and environmental harmonization. Regarding airport pavement, we will investigate methods for detecting the stripping of asphalt mixtures, measures to prevent such stripping, how the durability performance of airport pavement can be improved, and quick repair and rehabilitation techniques while construction quality, is still assured.

ii) Research on systems for inspecting and diagnosing infrastructure

We will conduct R&D on inspection and diagnosis techniques that utilize non-destructive and semi-destructive inspection methods and sensors, and unmanned investigation devices including ROVs. We will also study operation methods for inspection and diagnostic systems, etc. that leverage robots, drones, and other novel technology. Especially, we will propose a health monitoring system that utilizes sensors and also an efficient inspection and diagnosis method specific to each component and material type, and will also study efficient data analysis methods.

In addition, for piers, we will establish a scheme for selecting inspection and diagnosing methods according to the performance of structures to be evaluated and the accuracy of expected output.

iii) Research on maintenance and management systems for infrastructure

We will conduct accelerated deterioration tests of members of port structures, investigate performance deterioration models which cover the entire lifecycle of structures, and validate such models through exposure tests in actual environments and through on-site investigation. We will also take into account the required properties and utilization of individual structures, budgets, and various limitations, and then suggest strategies of management of port-based and district-based groups of port structures.

Activities in FY 2019

- We used long-term exposure facilities to study how to predict chloride-induced concrete deterioration, the electrolytic protection characteristics of steel bars in reinforced concrete, and the concentrated corrosion mechanism that affects steel materials. We also obtained data on the durability of various wood materials and reinforced concrete that utilized recycled aggregate.
- We aimed to establish a method for predicting the deterioration of protective coating methods against corrosion. To achieve this goal, we conducted continuous experiments at Hazaki Oceanographical Research Station, including exposure tests on steel pipe piles to which anti-corrosion protective coating had been applied, and also on hat-shaped sheet piles. We also conducted accelerated aging tests and exposure tests to further elucidate the deterioration mechanism of petrolatum coating methods.
- We evaluated the durability of concrete, in which low-grade aggregate (coral aggregate) and seawater as mixing water had been used, and conducted exposure tests to develop a concrete-curing technique using seawater. We also evaluated the durability of highly corrosion-resistant reinforcing steel and surface coating materials through exposure testing.
- To study the effects of steel wire mesh in airfield concrete pavements, we reviewed documents about the effects of steel wire mesh, the quantities in which it may be applied, available joint spacing variations, etc., and also conducted indoor experiments, etc.
- We studied the workability of the filling material solidification method for reinforcing existing caissons, and how their load-bearing and impact-resistant capacities would be affected by the improved strength and the scope of improvement. Also, to enhance the technique for repairing prestressed concrete components, we studied how their durability would be compromised by chloride-induced corrosion, and how their structural characteristics might be affected by repairs. We then systematically organized our findings on those elemental technologies, and proposed a design workflow (draft) for repairing and reinforcing concrete structures. In addition, we conducted experiments on the expansion caused by delayed ettringite formation, and studied and evaluated how it would be affected by water-shielding repair and restraining reinforcement methods.
- We conducted verification tests on monitoring by the inspection and diagnosis system using IoT in addition, we studied the feasibility of performing inspections using underwater drones and examined how such inspection method could be operated.
- We conducted experiments on ROVs for inspecting the superstructures of piers, and observed how their position measurement would be affected by waves and other external disturbances. In addition, we conducted on-site surveys using the ROVs while taking into account the waves and other site-specific conditions.
- To advance the process of formulating preventive maintenance plans for port and harbor facilities, we performed case studies on model piled piers, while formulating renovation scenarios (selection of an optimal renovation method and timing) based on which those piled piers can be converted into a preventive maintenance, using LCC, NPV, and $LCCO_2$ as evaluation indicators.

ROV for inspecting pier superstructures and its experiment in a water tank (with wave and current)

2C Research on Effective Use of Existing Infrastructure Facilities

Background and Objectives

- There is strong demand to improve the functions of existing infrastructure and use them effectively as possible. Requests include measures to handle increasing cargo volume and larger ships and vessels, diversification of airport functions, and countermeasures to deal with existing facilities which can no longer be used due to increased external forces and other reasons. In addition, regarding waste disposal sites at ports which accept industrial and non-industrial waste, there is social demand for the highly effective use of them. On the other hand, it has become difficult to secure disposal sites which accept soil dredged from water channels for shipping routes. Accordingly, it is necessary to prolong the life of soil disposal sites.
- Therefore, we will develop the following: techniques to improve the functions of existing infrastructure and to renew and efficiently change the intended use of existing infrastructure; techniques to reduce or effectively utilize construction byproducts; and techniques to effectively utilize waste disposal sites at ports.

Research Topics

Research and development comprise the following three sub-themes:

i) Research on techniques to improve or renew existing facilities

We have already conducted research and development on improving existing facilities including deepening existing quaywalls. However, such improvements were made using techniques for newly-built structures. Hereafter, we will investigate methods of evaluating ground characteristics, design methods, and geotechnical survey methods to improve and renew existing facilities. In such methods, the construction history, effects from neighboring structures, and other factors will be taken into account. We will also investigate ground evaluation methods and geotechnical information databases, both of which cover residual settlement and other phenomena, with the aim of long-term facility maintenance and management.

ii) Research on effective use and techniques of treating construction byproducts

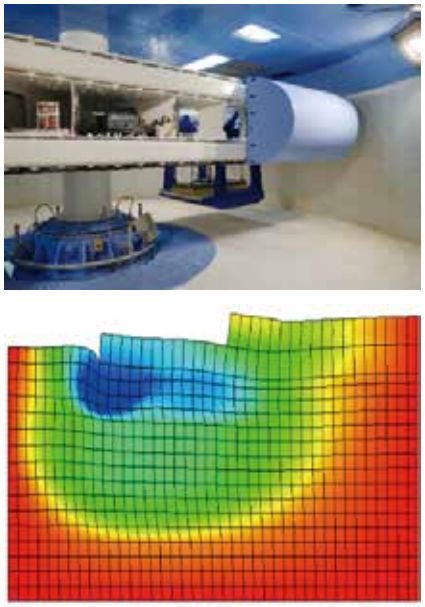
We will investigate the following techniques regarding dredged soil: improvement techniques to transform dredged soil into high-value added materials including composite soil, which provides habitats for benthic creatures, and solidified soil with high water permeability; and new volume reduction techniques. We will also investigate durability when solidified soil and slag composite soil are used in sea areas, the mechanical characteristics of composite ground materials containing various byproducts, crushable materials, and other contents, and methods of evaluating and managing the quality of these materials.

iii) Research on management and utilization of waste disposal sites at sea

Regarding disposal sites at sea, technologies for seepage control works for site development have been progressed. However, research on post-construction utilization of such sites has not been conducted. Therefore, we will investigate the following which are necessary for utilization: foundations, construction methods, effects on impermeable layers, management methods of the internal water level at low cost, techniques to detoxify waste before land reclamation, and the medium- to long-term strength and elution characteristics of solidified soil.

Activities in FY 2019

- As there were no effective methods for checking the status of improved objects underground in 3D in cases where the risk of soil liquefaction is addressed by injecting chemical grout into grounds with ununiform fine contents, we started examining methods for evaluating the quality of improved soils through geophysical exploration, and studied their effectiveness with the aim of establishing a suitable construction work management method. If such a method can be established, it will be likely to enable more sophisticated quality management during and after each construction work project and also promote i-construction. To this end, we combined indoor tests, on-site experiments, and numerical simulations to study the relation between the physical characteristics of improved soils and the datum measured during the geophysical explorations.
- We conducted scale model experiments to observe the plastic behavior of steel pipe piles and their bending behavior underground in order to obtain basic data for high definition of performance regulation of piers. In addition, we made a flowchart indicating the basic concept of design for improving sheet-pile-type mooring wharves.
- To visualize the microstructural features of original underground soils on site, we developed and produced a compact X-ray CT scanner and a special drilling machine that could capture underground images in situ on site.
- We conducted numerical analyses for typical cross sections to examine how increasing the height of a bank would alter deformation of its body, by changing conditons such as the height of raised dredged soil, distance between the temporary partition wall of raised bank and the sea wall, structural and mechanical properties of the temporary partition wall of the raised bank, countermeasures implemented on the seawall itself, etc. To achieve the aforementioned objective, we conducted a centrifugal test to verify simulation results and formulated a study method for raising a bank directly behind the seawall.



Development of technology for enhancing the capacity of a dredged soil disposal site
Top: centrifugal test, bottom: numerical simulation

3A Research on Development and Utilization of Oceans

Background and Objectives

- Since the 1960s, the importance of marine utilization and development has been pointed out. Various approaches for this purpose have been taken, but the progress remains inadequate. One of the reasons is the lack of infrastructure at sea as a hub. Therefore, marine hub ports should be constructed on remote islands including Minamitorishima Island and Okinotorishima Island to promote marine utilization and development.
- However, these remote islands are surrounded by severe sea wave environment and severe sea climate for port construction which are different from those of general ports in main islands. Further technological development is required to ensure smooth ship berthing, cargo-handling, and port construction.
- Therefore, in this research theme, we will make maximum use of previously accumulated knowledge regarding waves, sea-bed soils, port structures, and port construction to construct ports on remote islands, and will also promote marine utilization and development. Specifically, we will clarify the characteristics of waves in isolated reef areas, and will develop a new mooring system for ships. We will also develop technologies for downsizing and reducing the weight of underwater acoustic video cameras, as well as utilization and development.

Research Topics

Research and development comprises the following two subthemes:

i) Research on port construction and management in remote islands

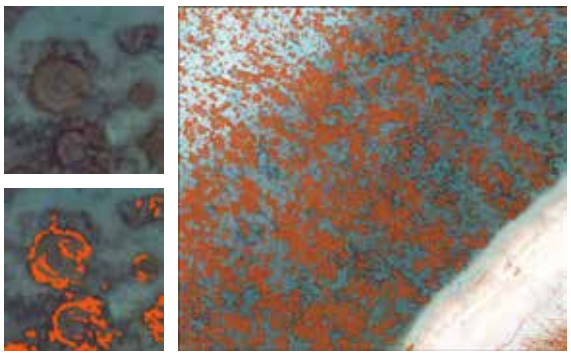
We will develop a numerical model for wave transformations on continental shelf boundaries and around isolated islands. We will also propose a technology to create calm water areas against wave propagation and long-period waves around isolated reefs. At the same time, we will develop a new mooring system applicable to remote islands to improve cargo-handling efficiency for ships.

ii) Research on infrastructure technology for utilization and development of oceans

We are trying to downsize and lighten underwater acoustic video cameras, and will also develop an unmanned underwater construction system to construct marine infrastructure. In addition, we will propose environmental conservation technologies utilizing calcifiers.

Activities in FY 2019

- For the research on wave-controlling technology that can be applied to isolated coral reef sea areas, we conducted planar model experiments to study the characteristics of wave transformation that normally occurs in isolated coral reefs, including how wave transformation occurs differently in relation to changing sea levels by tide, and also confirmed the reproducibility of the aforementioned phenomenon using high-resolution Boussinesq calculations. In addition, we corrected the calculation result based on what we had learned in those experiments as needed, and developed a tool that would enable us to estimate and display the spatial distribution of waves and currents over isolated coral reefs for various wave and current conditions that normally arise.
- For the technological development of the new mooring system for ships in ports, we suggested measures for resolving the previously identified technical issues with the aforementioned system, for application to remote islands, and also summarized our research findings obtained thus far.
- For the research on machine guidance technology used for underwater excavator, we conducted independent-element testing of mound-leveling attachment in actual sea areas, to verify the usability of the additional technology for remote operation. In addition, we evaluated a remote operation support system that integrated external measurement sensors and the attachment into machine guidance, and tested its usability by applying it to caisson mounds in Hirara Port.
- For the development of the next-generation acoustic imaging system, we conducted experiments on dredging and bottom mud replacement works in actual work areas. As for acoustic video cameras, we applied detailed adjustments as needed for each work type, and removed the strong noise affecting the captured images originating from the power supply in order to improve the image quality. In addition, as for the acoustic image viewing system, we created application software dedicated to each work type and also developed a viewer that updates the image along with the progress of the work being conducted, which enabled us to determine when the current seafloor height achieved the targeted value.
- For the development of analytical methods applicable to the topographic dynamics of carbonate islands, we conducted GNSS surveys, photographic surveys using RTK-equipped drones, multi-beam sounding, aerial photography using a combination of visible light and NDVI cameras, sediment and benthic organism sampling, seafloor topography surveys using green-laser drones, and surveys of coral larvae. In addition, we analyzed factors that facilitate topographical changes, developed prediction methods, studied the relation between coral growth and the surrounding environmental conditions, and developed a method using deep learning that could automatically determine the distribution of reef-forming organisms and their levels of activity.
- For the study of floating breakwaters equipped with a wave-power generation function, we conceptually evaluated the configuration of wave-power generation devices that would be integrated into floating breakwaters, and performed numerical calculations to examine the optimal shape of such breakwaters while taking into account the wave-dissipating capability of the wave-power generation devices.
- For the study of methods for calculating wave forces acting on offshore wind power plants, we evaluated the stability of the numerical calculation using CADMAS-SURF while varying the mesh size and time interval, so that we could calculate the wave force from the velocity and the acceleration of the water particles of progressive waves.
- For the study of wave force calculation methods applicable to offshore wind power plants, we reviewed the current designs of offshore wind power plants built on pile foundations, conducted repeated horizontal loading tests on piles set in saturated sandy ground in a large soil tank, and also conducted repeated horizontal loading tests on piles set in saturated clay ground at actual operation sites. Furthermore, we developed a numerical analysis code that could demonstrate the pile-driving (installation) process.



AI-powered automatic coral detection utilizing machine learning
1. Based on a sample image (top left), a correct (labeled) image (bottom left) is created.
2. Based on the labeled image, teaching data is created.
3. Machine learning occurs based on the teaching data.
4. Coral areas are automatically detected on the target image (right).

4A Research on Enhancement and Utilization of Coastal Ecology

Background and Objectives

- Rich ecosystems in coastal zones include tidal flats, seagrass meadows, and coral reefs. Coastal zones are valuable places for the global environment. However, during the era of rapid economic growth, intense socio-economic activities caused the deterioration of water quality in coastal inner bays and enclosed waters, resulting in ecosystem damage. Thanks to subsequent countermeasures, water quality has gradually been improving in some coastal zones; however, recovery of the coastal zone environment including ecosystems remains a formidable challenge.
- On the other hand, new challenges include the utilization of coastal zone functions for mitigating climate change, as well as countermeasures against large-scale oil spill incidents from maritime industrial complexes and other facilities.
- Therefore, in the themes of this research, we will conduct research and development with the following goals: further restoration of the coastal zone environment, coastal zone utilization for climate change mitigation, and establishment of technologies to counter large-scale oil spill incidents.

Research Topics

Research and development comprise the following three subthemes:

i) Research on coastal-ecosystem utilization

Regarding the ecosystem-based countermeasures against the impacts of climate change, we will conduct research on various phenomena that help suppress climate change, such as carbon sequestration/storage by coastal ecosystems (blue carbon), and their absorption of CO_2 in the atmosphere, in various domestic and international sea areas. We also plan to develop related technology on a global scale. We will also develop a technology to create coastal ecosystems which suffer less damage due to earthquakes and tsunamis and which recover rapidly. Through such technologies, we can continuously reap the benefits of the ecosystem.

ii) Research on the water-environment simulation and analysis in inner-bay

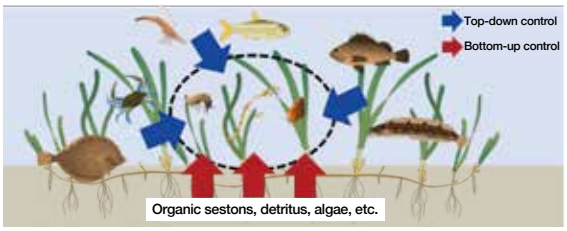
Regarding the acquisition and utilization of environment observation data, we will develop a new method for analyzing the marine monitoring data obtained from the ferries, monitoring posts, etc. that are currently in operation, and will also develop a new observation method that will allow us to effectively acquire certain types of environmental data for which conventional methods have not yielded sufficient results. We will also re-analyze existing underutilized environmental data, and will use multi-functionalized GPS wave-observation buoys to continuously observe areas for which environmental data has not been obtained. In addition, we will integrate weather/marine/ecosystem models and utilize in real time the environmental observation data. Through these means, we will develop a system which comprehensively predicts problems that frequently occur in inner bays, including red tides, blue tides, and hypoxia.

iii) Research on countermeasure technologies against sea oil spill

Regarding technologies for dealing with spilled oil, in addition to developing technologies to resolve conventional on-site challenges, we will conduct new research and development on the following: oil-gathering equipment loaded on next-generation oil-recovery ships; and systems which comprehensively recover or treat oil and which can address large-scale oil spill incidents. In addition, we will establish an information system for the risk management of oil pollution based on simulation technology, understand the behavior and mechanisms of oil spilled from dangerous facilities in waterfront areas due to natural disasters including earthquakes and tsunamis, and conduct research and development of quantitative prediction techniques and mitigation techniques for spilled oil. Through such approaches, we will develop innovative countermeasure techniques against oil pollution and improve the ability to respond oil pollution.

Activities in FY 2019

- As for the study on the global dynamics model for estimating the CO_2 absorption rates in shallow sea areas and inundation suppression effects, we developed and tested a global carbon circulation/ecosystem model and a wave and topography model, gathered topographic and ecosystem data for global estimation, and performed GIS analyses of such data. We also conducted in situ surveys and experiments on carbon dynamics in seagrass meadows, and performed analyses using numerical models.
- For the creation of coastal topography and geo-design that help both mitigate disasters and preserve ecosystems, we further improved the integrated assessment and prediction method applicable to the coastal ecosystems and geoenvironmental dynamics, elucidated how earthquake-induced soil liquefaction, storms, and waves could impact various types of benthic organisms in intertidal and subtidal zones in terms of how they would be transported, floated, and buried, and also their mortality rates. In addition, we evaluated and analyzed the performance of various geoenvironments, including recycled soil, to resist erosion and be used as a habitat by organisms.
- For the research on cross-sectional observation and analysis of atmospheric and oceanographic issues at bay mouths, we monitored wind conditions in the atmosphere and facilitated development of the cross-sectional observation system. In addition, we continued steadily with marine observation activities, examined the feasibility of applying satellite data to bay-mouth monitoring, and conducted on-site observations.
- For the dynamic analysis of macro-organisms in coastal ecosystem simulations, we created a code based on the formulation work done during the previous fiscal year, implemented the code in the Ise Bay simulator, organized data gathered during on-site observations related to current quantities, etc., and compared the data to the simulation results.
- For the development of technology to improve the functions of ecosystems in seagrass meadows, we obtained data on the fish community by utilizing environmental DNA, for which technical innovation has been advancing in recent years. In addition, we conducted feeding experiments on the fauna inhabiting seagrass meadows and assessed their value as food in order to evaluate the function of seagrass meadows as feeding grounds for fishes.
- For the numerical analysis of coastal currents using current simulation and data assimilation, we conducted numerical experiments in rectangular model sea areas, and verified that data assimilation can be done by using a method of adding noise to the boundary conditions to create their ensemble. In addition, we conducted data assimilation using actual water temperature data measured in Tokyo Bay and demonstrated that the water temperatures were corrected so as to approach the measured values.
- As for R&D on improving next-generation technology to mitigate oil pollution, we conducted model experiments to explore oil-gathering methods that might be suitable for adoption by next-generation oil recovery equipment, which involved using pressurized water jet suction and an excess water recycling system. In addition, we upgraded the network-adaptive oil movement prediction system to better estimate how marine oil spills are transported by the water. Furthermore, we studied a method of controlling oil spills using self-extracting bubble curtains.



Study of prey organisms in a seagrass meadow

4B Research on Coastal and Estuarine Processes

Background and Objectives

- PARI's research activity of littoral drift was started to examine the critical water depth of sediment movement for harbor planning. Now, prevention methods against sedimentation and also siltation are proposed. However, in Japan, sedimentation and siltation are still progressing in some ports, and in other countries which aim to expand their infrastructure overseas, a much greater amount of siltation than in Japan is projected. Countermeasures against such sedimentation and siltation problem have been inadequate.
- On the other hand, beaches are valuable as they provide protection, environment and utilization functions. However, the area of beaches has been decreasing since the era of rapid economic growth, and is still shrinking at a rate of 1.6 km^2 per year. Various countermeasures have been taken to prevent such coastal erosion, and as a result, the beach area has increased at some coasts. Nevertheless, global warming is expected to cause more severe coastal erosion. In addition, when remote islands and overseas are taken into account, it is important to maintain not only beaches but also coral-reef coasts.
- Therefore, in the themes of this study, we aim to maintain the following under future climate change: natural coastline geometry including beaches, mangrove coasts, and coral-reef coasts; and artificial coastline geometry including navigation channels and harbor basins, which support logistics. We will also estimate changes in coastal-erosion and sedimentation phenomena assuming the progress of global warming, and then propose countermeasures against those changes. Also, we will clarify siltation processes in the estuaries of large rivers, mangroves and intertidal zone in the Asian countries, and then propose countermeasures against such phenomena.

Research Topics

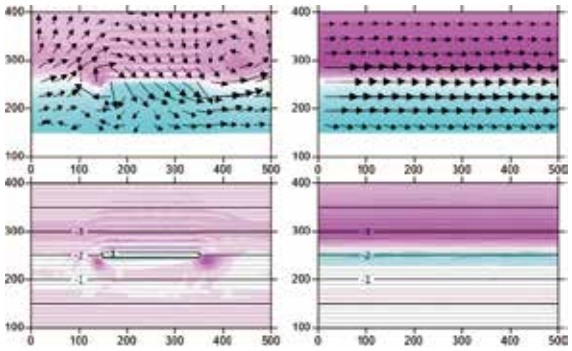
Our researches and developments for coastal protection and maintenance of waterways and mooring basins are as follows:

We will analyze long-term measurement data of the Hasaki coast and conduct short-term, intensive, on-site observation of how beaches respond to different sea levels. Through this, we will understand beach-response mechanisms to sea level rise, and will develop methods of predicting future beach morphology. We will take into consideration the spatial scale of not only the Hasaki coast but also global, and predict long-term coastal changes (including natural sand coasts, sand coasts protected by structures, coral-reef coasts, and pebble coasts) along with variations of coastal disaster risks. In addition, we will develop hybrid beach-maintenance methods, which minimize structure volume and actively introduce sand bypasses, and propose effective beach maintenance methods that account for the disaster risks.

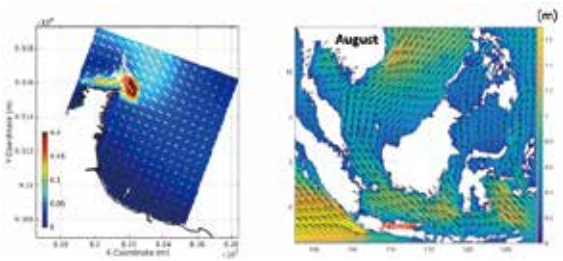
Regarding sediment transport which accompanies port utilization, we will expand the scope of our research to include estuaries of large rivers, mangroves, and intertidal zones over-seas. Then, we will develop monitoring method for topographic change which address regional characteristics and understand the dynamics of topographic changes. In addition, we will examine strategies to reduce siltation and sedimentation and will develop the efficient maintenance methods of navigation channels and harbor basins as well as conservation of the surrounding environment of port and harbor facilities.

Activities in FY 2019

- For the development of a method for predicting beach morphological changes along with climate change, we used the shoreline change model, which has been developed based on the observation data obtained at the Hasaki coast, and applied it to Omotehama Beach and Ocean Beach. In addition, we started organizing the beach morphological change data in France and the future scenario data for predicting the future coastal change in collaborating with French researchers.
- As for observation at the Hazaki Oceanographical Research Station and the development of a coastal topographic change prediction model, we continuously conducted on-site observation of wind, waves, currents, and topographic changes at the Hazaki Oceanographical Research Station. In addition, we performed calculations to estimate topographic changes that would arise around structures, using the topographic change prediction model.
- As for the study on the transportation of sediments around estuaries and their deposition processes in navigation channels and turning basins, we developed and applied a numerical model that can simulate the sediment transport caused by waves and tidal currents to actual coastal areas in Java Sea, Indonesia. In addition, we examined the dynamic characteristics of fluid muds, which have been observed in the Java sea and the Niigata Port, and the prevention methods for minimizing harbor siltation with the fluid mud.
- As for the applicability of airborne laser bathymetry for topographic monitoring in coastal areas, we studied survey methods to reduce data losses caused by turbid seawater and white foam. In addition, we developed a data reading program that could directly analyze waveform data of laser reflection intensity.



Calculation of currents with and without a submerged breakwater, and topographic change (with oblique waves with a height of 1 m and a cycle of 6 s)
Left: with a submerged breakwater installed on the seabed 2 m below sea level, with its top surface 1 m below sea level
Right: without any submerged breakwater
Top: Currents (arrows) and the mean sea level (light blue indicates elevation)
Bottom: Topographic change (red indicates areas of erosion)



Application of the sediment transport model around the Patimban Coast, Indonesia
(Left) Simulated tidal current field
(Right) Simulated wave field (arrows indicate wind direction and velocity; colors indicate significant wave heights)

Fundamental Research in FY 2019

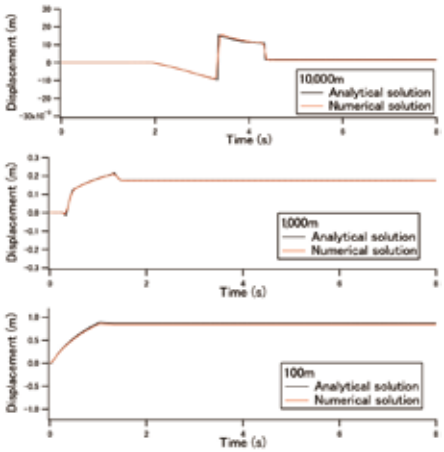
The fundamental research of waves, beaches, ground, earthquakes, environments, etc., is the basis of every study conducted by PARI, and therefore we are actively working on clarifying principles and phenomena, such as the mechanisms of natural phenomena and dynamic behavior of the ground and structures.

	Research theme (Fundamental research)
1	Strong motion earthquake observation in port and airport area
2	Investigation of earthquake disaster
3	Development of estimation method for near-fault strong ground motions
4	Study on the evaluation and analysis of liquefied ground behavior and effective countermeasures under sequenced earthquake motions
5	Study from geotechnical view-point on stability evaluation method of coastal structure subjected to high waves
6	Development of the estimation method for local scour around coastal structures due to tsunami
7	Elucidation of oceanographic phenomena based on central processing and analysis of observation data
8	Evaluation of longterm durability of concrete, steel and various materials based on exposure test
9	Evaluation of applicability of sustainable materials in the marine environment
10	Development of the performance evaluation method in protective coating for marine structures
11	Evaluation of the durability of various materials under severe environments
12	Study on process leading to rupture of pier structure for high definition of performance regulation
13	Enhancement of accuracy of method for evaluating mechanical properties of composite geomaterials based on microstructural feature
14	Development of analytical methods for the topographic dynamics of carbonate islands
15	Elucidation of the horizontal resistance characteristics of pile foundations for offshore wind power plants under various fluctuating loads
16	Validation of the newly developed global dynamic model for the projection of atmospheric CO_2 uptake rate and inundation control in shallow coastal ecosystems
17	Cross-sectional observation and analysis of atmospheric and oceanographic issues at bay mouths
18	Analytical study of macro-organisms dynamics on a coastal ecosystem simulation
19	Development of the methods for increasing ecosystem functions in eelgrass meadow
20	Developing future projection model of coastal change in the context of climate change
21	Observation of coastal phenomena at HORS and development of numerical simulation of topography change for port and surrounding beaches
22	Study on sediment transport in estuary and deposition process in navigation channel
23	Study on applicability of airborne laser bathymetry for topographic monitoring in coastal zone of sea shore

Cases of Fundamental Research

Development of estimation method for near-fault strong ground motions

- When a large crustal earthquake accompanies either a large slip near the earth's surface or a surface fault trace, ground motions arise that contain permanent displacements in the near-source regions. Ground motions containing such permanent displacements are often referred to as "fling steps." When the 1995 Hyogo-ken Nanbu Earthquake occurred, the ground motions observed in Kobe City did not contain significant fling-step components. However, during the 2016 Kumamoto Earthquake, the rupture of the fault reached the earth's surface, and significant fling-step components were observed in Komori, Nishiharamura, etc. near the fault. For those fling steps observed during the 2016 Kumamoto Earthquake, the rise time was as small as 2 s and they could have caused a significant response to structures. This highlighted the importance of fling steps once again.
- When calculating ground motions containing fling-step components, it is necessary to use a method that can precisely handle the boundary conditions at the free surface in order to accurately consider the difference in permanent displacement between the hanging wall and foot wall sides. The discrete wavenumber method is one such method: it allows precise calculation of ground motions for a half-space or a layered half-space. However, when applying the discrete wavenumber method to near-fault ground motions, various factors that affect the calculation result must be considered, one of which is the subfault size.
- In some of previous studies to verify the applicability of the discrete wavenumber method to near-fault ground motions containing fling-step components, the results of the discrete wavenumber method were compared with analytical solutions for the permanent displacement. However, there have been few cases where analytical solutions were obtained for displacement waveforms including the process that leads to permanent displacements. Hence, such verification by comparison with analytical solutions for displacement waveforms themselves has been little studied.
- Therefore, in this study, we used the analytical solution obtained by Masuda and Hikima, which is one of the few analytical solutions available as described above, to verify the effectiveness of the discrete wavenumber method for calculating near-fault ground motions. During this study, we examined the required subfault size among other conditions in order to achieve high-precision results. The aforementioned analytical solution pertains to ground motions for an elastic full space when a simultaneous slip occurs on a circular fault; it pertains to displacement components parallel to the slip direction at receivers along the central axis of the circle.
- This study revealed that using subfaults as small as 0.5 times the fault distance would yield sufficiently precise results. The figures below indicate the results of calculating displacement waveforms at distances of 10,000 m, 1,000 m, and 100 m from a circular fault with a radius of 1,000 m, using a subfault size of 50 m. Black traces indicate the analytical solutions and red traces indicate the results obtained using the discrete wavenumber method; they agree to each other quite well, indicating good calculation accuracy with these conditions.



Comparison of displacement waveforms at distances of 10,000 m, 1,000 m, and 100 m from the fault
Black traces indicate the analytical solutions and red traces indicate the results obtained using the discrete wavenumber method

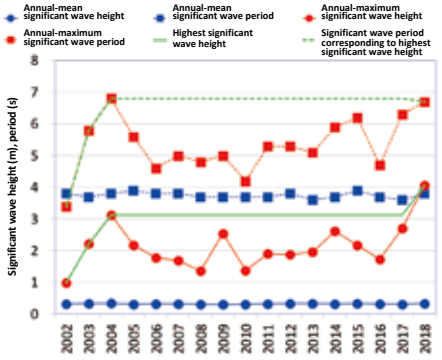
Development of the estimation method for local scour around coastal structures due to tsunami

- Local scours behind breakwaters and around breakwater heads are critical to the structural stability against a tsunami, but the amount of the scour remains difficult to estimate.
- Therefore, in this study, we will elucidate the mechanism of local scour by conducting hydraulic experiments, and establish a model to estimate the amount of the scour by applying a particle-based numerical simulation, etc.
- In FY 2019, we conducted a hydraulic experiment and numerical simulations to elucidate the phenomenon of local scour that will occur around the head of the bay-mouth breakwater which is planned to be built in Urado Bay, Kochi Prefecture.
- In this experiment, we installed a 1/40 scale model breakwater in our large experimental wave basin and used a pump to reproduce tsunami. We then measured the currents around the breakwater and the wave forces acting on the caisson. A fixed floor was used in this experiment.
- Meanwhile, we used the tsunami and storm surge simulator (STOC) to run simulations covering the large area extending from the tsunami wave source area to Urado Bay, and calculated the current velocity distribution at the mouth of the bay, which would be the boundary condition of the experiment. In addition, we found that the conventional calculation method, which approximated the breakwater as the demarcation line, tends to underestimate the current velocity and the amount of scour.
- Furthermore, to elucidate the characteristics of large eddies that occur around breakwaters, we performed 3-D calculations by applying the particle-based numerical simulation method, PARISPHERE. The results showed that the eddies around the breakwater head flowed to a diagonally downward direction, from upstream to downstream.
- In addition, we conducted experiments to study the scour that occurs behind a breakwater by a tsunami overflowing current, varying the rubble mound shape and the water level behind the breakwater caisson. The experiments revealed that the velocity of the overflow current increases and bends toward the caisson. The bend current hit not the sandbed but the rubble mound resulting in the suppression of the sandbed scour.

Experiment on currents around breakwater head

Elucidation of oceanographic phenomena based on central processing and analysis of observation data

- Since 1970, PARI has been constantly handling the routine work of centrally processing and analyzing the observation data obtained through the Nationwide Ocean Wave Information Network for Ports and Harbours (NOWPHAS). As the risk of climate change intensifies, it is crucial to continue performing the work well, and also to provide information that is closely related to works at ports, harbors, and coasts.
- To achieve these objectives, we perform central processing and analysis of observed oceanographic data in this research. More specifically, we will provide quick and final analysis on wave data observed at each observation station, summarize the wave statistical analyses in the Annual Report on NOWPHAS, and also store the tidal level and wind data.
- In FY 2019, we performed statistical analyses on the wave data obtained during 2018, and summarized the results in the Annual Report on NOWPHAS. During this year, the highest significant wave was updated at six observation stations; these are three coastal seabed wave gauges at Ise Bay, Shionomisaki, and Kobe as well as three GPS-mounted wave buoys off the coasts of Kaiyo in Tokushima, Cape Muroto in Kochi, and Hyuga in Miyazaki. Each of these locations set the new record because of the typhoons (Jebi and Trami) that made landfall in the Kinki region in September 2018.
- We will continue with our work of producing the Annual Report on NOWPHAS, analyzing significant tsunami and wave events, and improving related data processing and analysis methods, in order to positively contribute to facility design and disaster prevention at ports, harbors, and coasts.



History of wave statistics at Ise Bay station of NOWPHAS
(Highest significant wave height was updated for the first time in 14 years, since observations started in 2002)

Evaluation of applicability of sustainable materials in the marine environment

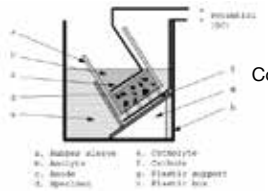
- In order for us to achieve a sustainable society, it is desirable to reduce the usage of natural resources and cut CO_2 emissions when new structures (mainly concrete ones) are built. In addition, it is necessary to improve the performance of such structures and extend their usable lifespans, to increase the safety margin for their time-induced deterioration and ability to withstand natural disasters.
- One possible action to achieve these objectives is to utilize recycled materials (various slag aggregates, blast-furnace slag fine powder, fly ash, etc.), which is a clear and effective approach. However, there are few instances where such approach is taken. Reasons why such action is not taken often enough include the fact that performance requirements, especially of structures made of non-reinforced concrete (i.e., blocks, superstructures of breakwaters, etc.), are not clearly defined, and also a lack of any established method for evaluating their long-term durability, etc.
- In addition, greater use of more environment-friendly construction materials is desirable to reduce the negative environmental impacts. However, few research projects have studied the environmental compatibility of various materials.
- To solve this problem, we will mainly tackle the following tasks.
- Multifactor evaluation of concrete performance involving recycled materials (workability, durability, etc.)
- Organization of information on the performance requirements of concrete structures to be built at ports and harbors (mainly focusing on non-reinforced concrete) and formulation of a method for evaluating their long-term durability.
- Evaluation of environment-friendly materials (especially recycled materials) (While most previous studies focused on evaluating durability, we will adopt a more comprehensive approach that also considers environmentally negative effects (CO_2 emissions, etc.).)

Caisson (RC) is simulated

Parapet (non-reinforced) is simulated

Experiment on concrete made of high-density recycled aggregate (copper slag fine aggregate)
(The concrete was produced at an actual plant and then transported and placed using a concrete pump)

Indoor test



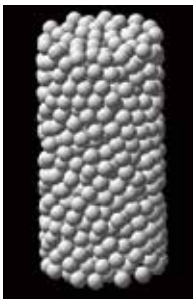
Comparison

Marine exposure test

Accelerated evaluation of chloride ion permeability of concrete utilizing blast-furnace slag fine powder (Comparison between indoor and marine exposure tests)

Enhancement of accuracy of method for evaluating mechanical properties of composite geomaterials based on microstructural feature

- Geomaterials with different grain size distribution, particle shape, and other micro-structural features exhibit various mechanical properties due to those features. In addition, even if soil specimens are sampled from the same geological stratum or prepared in a similar manner, the test result may vary depending on their micro-structural differences. Therefore, evaluating the effects of such micro-structural features will lead to advances in methods for evaluating the mechanical properties of the ground. In the conventional geotechnical investigation method, undisturbed samples (i.e., cores) are taken from the original ground, after which various types of laboratory tests must be performed to measure their properties, etc. depending on the purpose. On the other hand, if it were possible to use an X-ray CT scanner to acquire images of the micro-structural features of the ground, perform CT image and numerical analyses, and conduct simulated soil tests using 3D printing technology, it would enable the evaluation of the various mechanical properties of the core samples, which would be highly useful in practice.
- We performed uniaxial and triaxial compression tests on simulated specimens created using 3D printing representing the particles and their sedimentary structures, and confirmed that they exhibited a granular ground behavior resembling a ground.
- We applied the original data (shape and location data of each particle) on the simulated specimens as a numerical analysis model and attempted to reproduce the compressing movement.

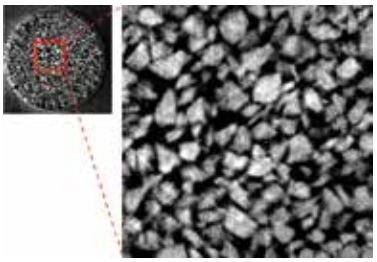


Particle structure of the numerical analysis model

Compression test on a simulated specimen having the identical particle structure

- A compact X-ray CT scanner and an excavator were developed and produced in order to capture images of the soil microstructure of ground on site.

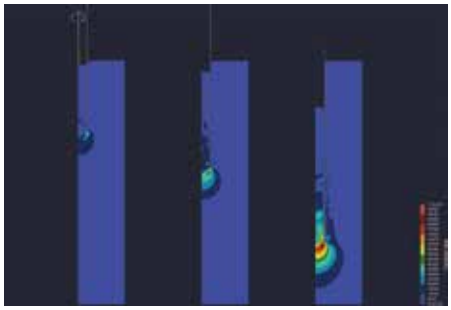
Compact X-ray CT scanner



CT image of gravel (grain diameter of 2 to 5 mm)

Elucidation of the horizontal resistance characteristics of pile foundations for offshore wind power plants under various fluctuating loads

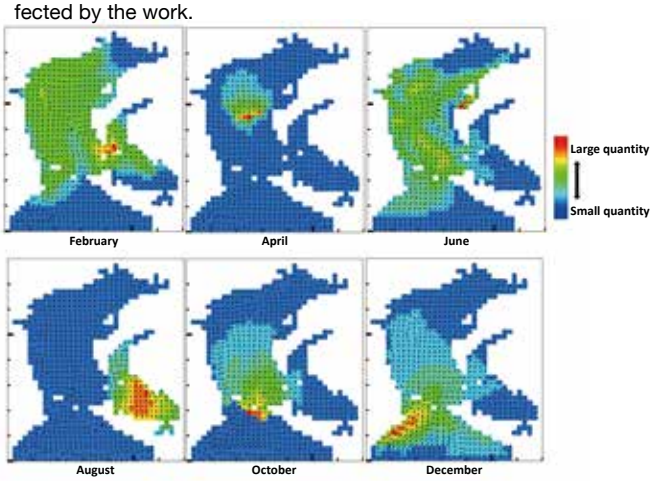
- Offshore wind power plants that are built directly on the seabed are subjected to a variety of variable loads simultaneously for extended periods, including wind, waves, earthquakes, etc. As each such variable load has a unique load amplitude, frequency band, number of repetitions, acting position, etc., the horizontal load affecting pile foundations also consists of complex factors.
- In practice, the beam spring model in which the lower ends of piles are fixed has been mostly used. However, as it is unclear whether large-diameter piles could exhibit a similar resistance mechanism, the non-linear ground spring model that is used cannot demonstrate the deformation characteristics of ground that are manifested when subjected to repetitive loads. In addition, as it has not yet been clarified the change of mechanical properties of ground during pile-driving, at present we must treat ground as virgin ground for design purposes.
- Therefore, the objective of this study is to evaluate bearing capacity while taking into consideration the history of pile-driving and external variable loads for offshore wind power plant having a pile foundation.
- During this fiscal year, we produced test equipment that can apply horizontal loads to the piles, utilizing the large soil tank experiment planned for execution in the next fiscal year, and also developed a numerical analysis code that can simulate the pile-driving process.



Numerical simulation of a pile-driving process (shear strain distribution and axial symmetry analysis)

Analytical study of macro-organisms dynamics on a coastal ecosystem simulation

- Inner bays in Japan such as Tokyo Bay and Ise Bay experienced industrial development and population growth during the post-war period of high economic growth, which caused large amounts of nutrients to be transported from rivers into those inner bays, causing eutrophication. Although the regulation on aggregate amount that was subsequent enforced improved the situation to some degree, the decreasing amount of fish caught in the inner bays remains a problem, the root cause of which is yet to be identified.
- The objective of this study is to simulate fish dynamics by integrating a fish ecosystem model into the Ise Bay simulator comprised of a current model and a lower-trophic-level ecosystem model.
- We developed a fish ecosystem model that could be run on the Ise Bay simulator, and performed calculations to simulate fish dynamics present in Ise Bay. Application of this model not only allowed us to produce short-term results but also prove that it could perform calculations for whole years.
- This model is also applicable to other inner bays besides Ise Bay, and is expected to play an important role in fishery resource management in various sea areas. For example, if a coastal sea area is to be developed and there is a fish species that uses the sea area only during a specific season, we could create a work schedule to avoid disturbing the fish during that season, and manage the overall work process in consideration of the creatures and the environment that could be affected by the work.

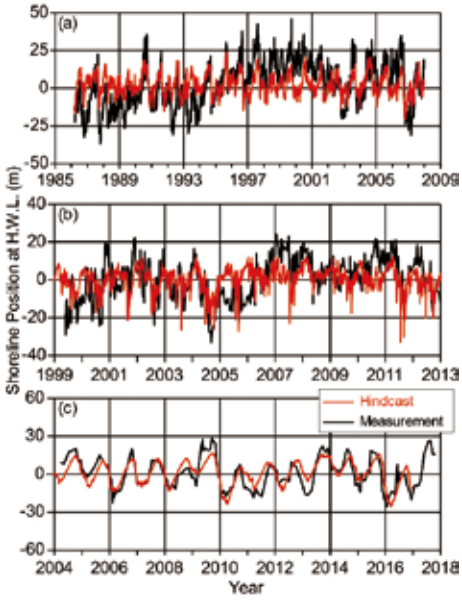


Simulation of distribution of adult Japanese anchovy (*Engraulis japonicus*) population

- We will attempt to improve the calculation precision using a parameter tuning system. It is also important to accumulate data on the existing fish species utilizing fish-finder data, environmental DNA, and other related technology.

Developing future projection model of coastal change in the context of climate change

- In response to the rising sea levels and changing wave climate that are expected to occur due to climate change, the beach morphology at the end of this century will change drastically. Hence, to manage the risk of coastal disasters with a long-term view and to devise appropriate countermeasures, we must be able to predict the future beach morphology with sufficient precision.
- In this study, we use observation data acquired from various beaches around the world and develop a model that can predict future shoreline changes caused by climate change.
- In FY 2019, we applied the shoreline change model to Hasaki Coast in Ibaraki Prefecture, Omotehama Beach in Aichi Prefecture, and Ocean Beach in California, U.S.A. to check the model's reproducibility. While the precision of the reproduction achieved by our model was fairly good, the model parameters need to be made more generally applicable. We will endeavor to resolve this issue in order to better predict global beach morphological changes in the future.



Shoreline changes hindcasted by the model
(Top: Hasaki Coast, middle: Omotehama Beach, bottom: Ocean Beach)

Exploratory Research in FY 2019

In FY 2019, exploratory research projects based on ingenious and/or advanced ideas that could potentially lead to new research fields for PARI in the future were carried out.

A basic study on application of underwater drone and 3D data for inspection and diagnosis of marine structures

- In this study, we conducted an on-site experiment on existing underwater drones, 3D data, etc. to examine the applicability of them and to identify issues that must be addressed, with the aim of developing an efficient and effective inspection method for the underwater components of marine structures.
- As underwater components of structures are generally covered by marine creatures, we found it difficult to visually check the condition of components only with the underwater drone. However, we found it possible to apply the underwater drone for the preliminary inspection, which is to determine the area where to perform detailed inspections such as the thickness measurement of steel pipe piles. Therefore, underwater drones might contribute to the labor-saving and effective inspection and diagnosis.
- We captured serial images on a steel pipe pile but were unable to generate a 3D model from images within the scope of this experiment. Possible causes of this failure might be the less distinctive features acquired from each image, the murkiness and floating objects in the water that prohibited us from acquiring clear images, and the waves and tidal currents that constantly shook the underwater drone and prevented it from capturing images stably.

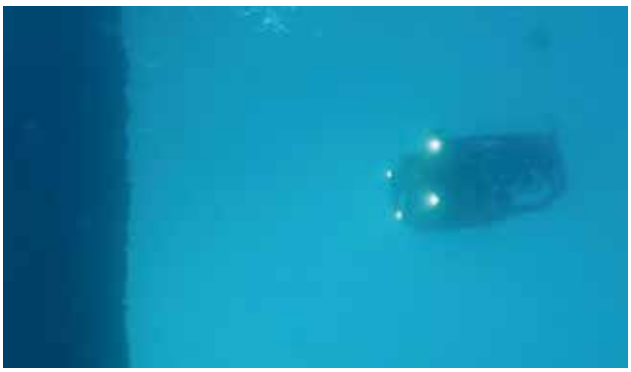
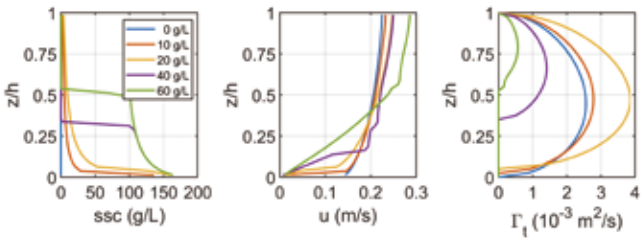


Image of an underwater drone capturing images of structural components

Development of a sediment transport model that considers the 3D dynamics of fluid mud

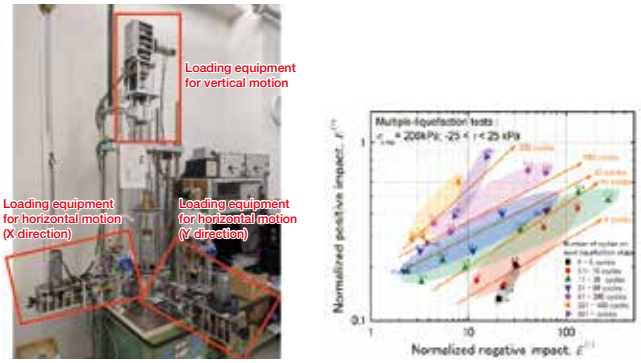
- In ports and harbors located near estuaries, siltation (deposition of mud) in shipping routes and basins could pose an issue in some circumstances. Therefore, it is important to develop a sediment transport model that can accurately predict mud transport processes for efficient maintenance and management of ports and harbors (e.g., dredging shipping routes and basins). It has been reported that the fluid mud formed on top of the consolidated bed affects the result of acoustic sounding using multibeam sonar, etc. Therefore, we must also understand and predict the formation processes of fluid mud that occurs with the accumulation of suspended mud. In this study, we developed a sediment transport model that can consider the vertical structure of high-concentrated mud including fluid mud and the flow structure depending on the mud concentration.
- We successfully simulated the formation processes of fluid mud and the flow structure depending on the mud concentration, by implementing into the model the following key factors for simulating the movement of high-concentrated mud: (i) flocculation of mud particles and hindered settling of high-concentrated mud; (ii) buoyancy effect caused by the mud concentration gradient; (iii) self-weight consolidation of fluid mud; and (iv) non-Newtonian fluid movement of fluid mud.



Simulated mud concentration, flow velocity, and vertical eddy diffusivity
(Numerical configuration: initial concentration as indicated in the legend, depth-averaged flow velocity of 0.2 m/s, after one day)

Analysis of the re-liquefaction characteristics of sand with a history of various types of shear including multi-directional shear based on dissipated energy

- Most of the previous studies on how shear history affected the re-liquefaction characteristics only considered one direction under plane strain; few studies examined the shear history considering the multi-directional seismic motions.
- To investigate the re-liquefaction characteristics of sand subjected to a multidirectional shear history, we developed bi-directional shear test equipment that could conduct simple shear in multiple directions. We chose loading equipment with an electromagnetic clutch, of which a gap on the loading axis is minimize, so that it could perform fine repetition and stopping operations in a precise manner. Further, this apparatus hardly showed backlash when the loading direction was reversed, which enabled liquefaction tests to be conducted precisely.
- To quantitatively evaluate the effect of various types of shear history on the re-liquefaction characteristics of sand, we calculated an index based on dissipated energy during shear loading from the relation between the stress ratio and the strain. This index was found to show a rational relation to the re-liquefaction characteristics. This energy index can be divided into two types of component. The one enhanced the re-liquefaction resistance of sand and the other reduced. We found that the number of repetitions of shear loading which causes re-liquefaction can be estimated based on the relation between these two types of components obtained from the shear history.



(Left) New high-precision bi-directional shear test equipment developed in this study
(Right) Relation between two types of energy components and the number of repetitions of shear loading which caused re-liquefaction

Challenging research toward building infrastructure in the deep sea: Evaluation of the physiochemical stability of concrete in the deep sea

- As Japan's territorial oceans and exclusive economic zone (EEZ) are around 12 times larger than its territorial land area, the country's ability to utilize its deep-sea resources is expected to radically improve its global competitive advantage. While the types of concrete being used to build marine infrastructure in shallow sea areas could be also used in the deep sea, there is a risk that conventional concrete might deteriorate faster in the deep sea.
- To address this issue, in this project we conducted experimental studies focusing on two points, the physical damage caused by hydraulic pressure and the chemical deterioration caused by low-temperature sea water, in order to evaluate the physiochemical stability of concrete in the deep sea.
- As concrete is a porous material, it is susceptible to the movement of liquid water through microscopic pores and resulting changes in the stress distribution, which could cause physical damage. Therefore, we developed new equipment that could withstand high hydraulic pressure (maximum 20 MPa at a water depth of 2,000 m) and capture images of the internal structure of specimens using micro-X-ray CT technology (Figure 1). The physical damage caused to the specimens by the water pressure was evaluated, based on the image analysis.
- Cement paste was immersed in low-temperature sea water and then the progress of its chemical deterioration was observed. It was revealed that rapid deterioration of the cement paste was found at low-temperature sea water, and the mechanism of rapid deterioration was estimated on the basis of thermodynamic phase equilibrium calculations.

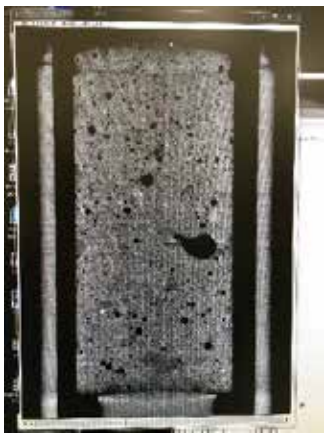


Figure 1: CT image captured by the equipment developed in this research project

Development of a real-time mapping system for indicating the degree of damage to pier floor slabs, utilizing mobile cargo-handling machinery

- Since the piers in ports are used for logistics activities, it is difficult to stop such operations to inspect the piers, both for economic reasons and also for avoiding disruption to citizens' daily lives, as large quantities of supplies are loaded/unloaded and transported every day.
- In this study, we obtained AE data from the operation of mobile cargo-handling machinery as it traveled regularly from one location to another, and performed analyses for formulating a measurement method for evaluating the degree of damage and developing a way of automatically determining the level of damage by using data obtained from AE activities.
- For data measurement, we drove the vehicles around while setting the area of damage or non-damage as a parameter. By using the data obtained from multiple sensors (four or more in this project) to detect the elastic waves that occur during such vehicle operation, we identified the points of excitation where elastic waves originated from the damaged locations. We then categorized the obtained data into several different clusters, and formulated a method for determining the degree of damage. More specifically, we adopted *k*-means clustering, which is an unsupervised machine learning method, and used it to conduct the cluster categorization using the feature amounts extracted from those elastic waves. As a result, we found that by conducting the cluster categorization based on the feature amounts of the data obtained from the power spectrum (Figure 1), the cluster categorization could be done based on the degree of damage detected. In particular, as shown in Figure 2, when we assumed the number of clusters was four and applied *k*-means clustering, we could achieve cluster categorization of varying degrees of damage that corresponded to the mean AE energy and the number of AE hits.
- In the future, we will study measurement methods that can take actual site conditions into account, develop a system to be able to make real-time determination, and also research location information systems.

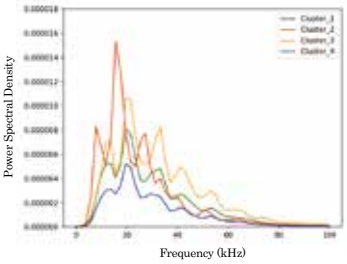


Figure 1: Power spectrum

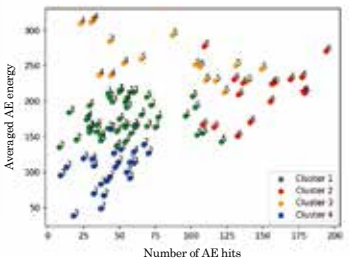


Figure 2: Cluster categorization result

Number of Peer-reviewed papers in FY 2019

Number of papers in Japanese	Number of papers in non-Japanese languages	Total	Rate of papers in non-Japanese language
48 (36)	53 (22)	111 (58)	47.7% (37.9%)

* The above numbers contain proceedings that only reviewed the abstract. (Numbers in parentheses indicate the number of journals.)

Papers Published in PARI Reports in FY 2019

No.	Title	Author(s)	Language	Month/Year
58-1-1	Development of Analysis Method of Moored Ship Motion in 3D Fluid Field	Yasuhiro AIDA, Katsuya HIRAYAMA	Japanese	August 2019
58-1-2	Strong Motion Simulation with the Pseudo Point-source Model for Intraslab Earthquakes	Atsushi NOZU, Yosuke NAGASAKA	Japanese	August 2019
58-2-1	Development of Visualization Method of Inter-particle Force Distribution by Using Mechanoluminescent-coated Particle and Its Application	Akihiko KONDO, Daiki TAKANO, Eiji KOHAMA, Richard J. Bathurst	Japanese	February 2020
58-2-2	Development of Seismic Improvement Method for Pile Supported Wharf Utilizing Existing Pile	Akihiko KONDO, Eiji KOHAMA, Yasuhiro TAKAHASHI, Hideki YOSHIDA, Kenji WATANABE, Hayato KOKUSHO, Shun AMANO, Moemi OYAMA, Shohei NAGASE, Takao FUJISAWA, Nobuyuki OKAJIMA, Tetsushi ABE, Masashi INOUE, Tohru YOSHIHARA, Mutsuro TSUKUDA, Tomoyuki UEDA, Noriyoshi HARATA, Naoya NAGAO, Shin OIKAWA	Japanese	February 2020

Papers Published in PARI Technical Notes in FY 2019

No.	Title	Author(s)	Language	Month/Year
No.1353	Development of Hydro-Geotechnical Centrifuge PARI Mark II-R	Hidenori TAKAHASHI, Naruhiko FUJII, Yoshiyuki MORIKAWA, Daiki TAKANO	Japanese	August 2019
No.1354	Development of a New Compaction Grouting Method with Improved Upheaval Control and Efficacy of Liquefaction Countermeasures	Shinji SASSA, Hiroyuki YAMAZAKI, Takeshi KONISHI, Masaki ADACHI, Takashi SHINSAKA, Kanji TAKENOUCHI, Hiroki MOROHASHI, Hidenori SAITO, Hiroshi OKADA, Keita TAKADA, Shingo WATANABE, Chikai KANEKO, Tadashi TAKAHASHI	Japanese	August 2019
No.1355	Physical Environment Concerning Hard Clam's (*Merterix lamarckii*) Survival at Kashima-nada Open Sea	Shin-ichi YANAGISHIMA, Satoshi NAKAMURA, Masayuki BANNO, Yukio YAMAZAKI, Hiromi HANZAWA, Toru UDAGAWA, Koichi SUGIMATSU, Ryogen NAMBU, Hideki SAWADA, Satoshi TAKEWAKA	Japanese	August 2019
No.1356	Annual Report on Strong-Motion Earthquake Records in Japanese Ports (2017)	Yosuke NAGASAKA, Atsushi NOZU	Japanese	August 2019
No.1357	Annual Report on Nationwide Ocean Wave Information Network for Ports and Harbours (NOWPHAS 2017)	Koji KAWAGUCHI, Fumikazu SUEHIRO, Takashi FUJIKI, Hitoshi TAMURA	Japanese	August 2019
No.1358	Validation of Third-generation Wave Models in Terms of Ocean Swells	Hitoshi TAMURA, Koji KAWAGUCHI, Takashi FUJIKI, Fumikazu SUEHIRO	Japanese	August 2019
No.1359	Proposal of Pile Connection Method with Precast Superstructure for Port Pier	Yuichiro KAWABATA, Katsuya IKENO, Ema KATO, Mitsuyasu IWANAMI	Japanese	August 2019
No.1360	Examination of Accuracy of Photogrammetry of Coastal Area by UAV	Shingo KAWAGUCHI, Kojiro SUZUKI, Naoki TSURUTA, Shota ASAHI	Japanese	November 2019
No.1361	Diversity Indices in Marine Invertebrates: Comparison of Two Types of Sampling Efforts	Shinya HOSOKAWA, Kyosuke MOMOTA	Japanese	November 2019
No.1362	Long-term Exposure Test of Concrete Using Surface Coating Materials and Epoxy Resin-coated Rebar in Naha Port Road Bridge	Toru YAMAJI, Nobuyuki KINJOH, Jun TOMIYAMA	Japanese	November 2019
No.1363	Axial Resistance of Steel Pipe Piles Installed and Cemented to Bedrock by Piling Rig with Twin Coaxial Rotary Head	Takaaki MIZUTANI, Masaaki KOJIMA, Kazuyuki MURAKAMI, Hirofumi MIGITA, Haruhiro MARUYAMA, Hiroyuki HASHIMOTO, Takefumi ISHIDA	Japanese	November 2019
No.1364	Model Test for Effect of Installation Process and Shape of Piles on Pullout Resistance of Open-Ended Piles	Keita NAKAMURA, Yusuke MOTOMIZU, Satoshi MATSUMURA, Takaaki MIZUTANI, Satoshi SHINGAI, Eiji OSHITA, Naoaki SUEMASA	Japanese	November 2019
No.1365	Field Test on Validation Accuracy of Residual Displacement Measurement Method after Earthquake for Mooring Facilities	Yosuke OHYA, Eiji KOHAMA	Japanese	February 2020
No.1366	Study on Strength Evaluation Technique by Using In-situ Tests on Chemical Grouted Ground as a Countermeasure for Liquefaction	Takahiro SUGANO, Kouki ZEN, Naoaki SUEMASA, Yasuo KASUGAI, Hiroyuki YAMAZAKI, Kentaro HAYASHI, Shun-ichi SAWADA, Toshio ENDO, Takaki KATO, Hiroshi NAKAGAWA, Hiroyoshi KIKU, Emi YAMAGUCHI, Noriyuki FUJII, Kanae BABA, Teruhisa FUJII, Keita TAKADA	Japanese	February 2020
No.1367	A Study of Calculation Conditions of Data Assimilation for Flow Analysis of Closed Waters by Ensemble Kalman Filter	Yoshitaka MATSUZAKI, Tetsunori INOUE	Japanese	February 2020
No.1368	Analysis of Lower Trophic Ecosystem Model and Fish Catches Using a New Fish Ecosystem Model	Tetsunori INOUE, Takashi KOMURO	Japanese	March 2020
No.1369	Recent Findings in Concentrated Corrosion and Cathodic Protection in Marine Steel Structures	Toru YAMAJI, Hiroto TADO, Yoshiyuki KAWASE, Atsushi KOBAYASHI, Michio YOSHIDA	Japanese	March 2020
No.1370	Development of Displacement Measurement and Stability Evaluation Support System of Mooring Facilities after Earthquake by RTK-GNSS	Hirotaka ITO, Eiji KOHAMA	Japanese	March 2020
No.1371	Annual Report on Nationwide Ocean Wave Information Network for Ports and Harbours (NOWPHAS 2018)	Koji KAWAGUCHI, Fumikazu SUEHIRO, Takashi FUJIKI, Hitoshi TAMURA	Japanese	March 2020

Annual Report, Technical Journals, and Website

The PARI Technical Journal

The Annual Report 2019 (Japanese version) and the PARI Annual Report 2019 (English version), which summarized the activities in FY 2018, were produced as a record of achievements, and were distributed to the parties concerned and published on PARI's website.

Regarding the PARI Technical Journal, we selected special articles for each study theme for every issue to introduce utilization situations of study results and PARI's experiment and on-site observation facilities. Approximately 2,000 copies of the PARI Technical Journal were distributed to approximately 1,600 places.

On PARI's website, we provided various information on events and news including PARI's summarized information, achievements, facilities, symposiums on a real time basis; we got approximately 130,000 accesses in this fiscal year.

Lectures for the General Public

Port and Airport Technology Lecture

Aiming to present and disseminate the achievements of investigations, research, and technical developments carried out at PARI, we held a Port and Airport Technology Lecture in Tokyo on October 11, 2019 in cooperation with the National Institute for Land and Infrastructure Management, which was attended by 150 participants.


Presentation by a PARI researcher

Port and Airport Technology Special Lecture in Region

Aiming to widely provide information on the research activities and achievements of PARI and collect information such as research needs in each region of Japan, we held 4 lecture meetings throughout Japan in cooperation with the National Institute for Land and Infrastructure Management, Regional Development Bureaus, and others, gathering approximately 600 participants.

Port and Airport Research Symposium

We held the Port and Airport Research Symposium in cooperation with the National Institute for Land and Infrastructure Management in Yokosuka City on January 17, 2020, which was attended by more than 100 people.

Open House

Open House

During the Open House event held on July 20 (Sat), 2019, which was jointly hosted with the National Institute for Land and Infrastructure Management (NILIM), we held a variety of demonstration experiments including one titled "Let's Feel the Power of a Giant Tsunami!," set up experiential areas such as one titled "Let's Observe Marine Creatures' Functions!," and arranged exhibitions such as one titled "Let's Learn Using a Drone Simulator!" The event was attended by a total of 870 visitors.



Open House set-up

Other Facility Tours

Other than the Open House, we held 59 facility tours, with 1,833 visitors. We introduced PARI facilities and PARI-associated research to visitors from private companies, the government, municipalities, and educational institutions to broaden understanding of PARI's activities and the social importance of researchers. We also carried out activities to increase understanding of disaster prevention, such as providing various information on earthquakes and tsunamis.

Other Outreach Activities

Cooperation with Super Science High school (SSH) Projects

For first- and second-year students from Kanagawa Prefectural Yokosuka High School which is SSHs designated by the Ministry of Education, Culture, Sports, Science and Technology, we explained our studies and organized tours to PARI's facilities to enhance students' interest in science and math.


Students listening to an explanation on test specimens used in experiments

Awards for Papers and Others in FY 2019

	Name	Award	Institution	Date	Remarks
1	Toru YAMAJI Director, Structural Engineering Department Kazuhide YONAMINE Researcher, Materials Group and eight others	Japan Society of Civil Engineering, FY2018 Distinguished Paper Award	Japan Society of Civil Engineers	April 5, 2019	Studies on the cathodic protection characteristics in seabed soil and the cathodic protection design of the port steel structures in consideration of the soil reactivity
2	Yuichiro KAWABATA Senior Researcher, Structural Mechanics Group	FY2019 the Commendation for Science and Technology by the Minister of Education, Culture, Sports, Science and Technology (The Young Scientists' Award)	Ministry of Education, Culture, Sports, Science and Technology	April 17, 2019	Research on control of concrete expansion and deterioration based on structural analysis
3	Takahiro NISHIDA Senior Researcher, Materials Group	FY2018 Society of Materials Science, Japan, Kansai Branch Manager's Award	Society of Materials Science, Japan (public interest incorporated association), Kansai Branch	April 18, 2019	
4	Yuichiro KAWABATA Senior Researcher, Structural Mechanics Group and two others	Ports & Harbours Association of Japan, FY2019 Distinguished Paper Award	The Ports & Harbours Association of Japan	May 22, 2019	Development of technology applicable to the pile-connection areas of precast superstructures utilizing the sleeve tube type method
5	Sayuri MATSUMOTO Head, Sensing and System Technology Group Kageyoshi KATAKURA Visiting Researcher, Sensing and System Technology Group Tomoo SATO Postdoctoral Researcher, Sensing and System Technology Group Muneo YOSHIE Senior Director for Research	Marine Acoustic Society of Japan Distinguished Achievement Award	Marine Acoustic Society of Japan (corporation engaging in specified non-profit activities)	May 30, 2019	High-resolution audiovisual data acquisition system
6	Yuri SUGIYAMA Researcher, Soil Mechanics and Geo-Environment Group	FY2018 Japanese Geotechnical Society, Research Encouragement Award	Japanese Geotechnical Society	June 7, 2019	Analytical investigation of disturbance on seabed-sampled soil specimens and its influence on unconfined strength
7	Takahiro NISHIDA Senior Researcher, Materials Group	Presentation Award	4th International Symposium on Concrete and Structures for Next Generation	June 18, 2019	
8	Tomohiro KUWAE Head, Coastal and Estuarine Environment Research Group and one other	FY2019 Japanese Association for Coastal Zone Studies, Publication and Culture Award	Japanese Association for Coastal Zone Studies	July 19, 2019	Blue Carbon: CO_2 Uptake and Carbon Storage in Shallow Coastal Ecosystems and Their Utilization
9	Technical Emergency Control (TEC) Force, Port and Airport Research Institute, National Institute of Maritime, Port and Aviation Technology	2019 Prime Minister's Commendation to Contributors for Disaster Prevention	Cabinet Office	September 20, 2019	2018 Dispatch of TEC-FORCE following the Hokkaido Eastern Iburi earthquake
10	Hidenori TAKAHASHI Head, Soil Stabilization Group Yoshiyuki MORIKAWA Director, Geotechnical Engineering Department and two others	Telford Premium Prize (Distinguished Paper Award)	Institution of Civil Engineers (ICE), U.K.	October 4, 2019	Thirty-seven-year investigation of quicklime-treated soil produced by deep mixing method
11	Toshinari TANAKA Senior Researcher, Robotics Group Ema KATO Head, Structural Mechanics Group Shuji NOGAMI Senior Researcher, Structural Mechanics Group	19th Symposium on Construction Robotics in Japan, Outstanding Paper Award	Council for Construction Robot Research (CCRR)	October 10, 2019	Field test of ROV equipped with tele-operation assistance functions for inspection of concrete pier superstructure
12	Shinji SASSA Head, Soil Dynamics Group	3rd Infrastructure Management Award, Special Award	Six Ministries (Ministry of Land, Infrastructure, Transport and Tourism; Ministry of Internal Affairs and Communications; Ministry of Education, Culture, Sports, Science and Technology; Ministry of Health, Labour and Welfare; Ministry of Agriculture, Forestry and Fisheries; Ministry of Defense)	November 7, 2019	Method for reducing waves passing through caisson joints to suppress washout and collapse of seawalls and quaywalls and to extend the service life of port and harbor structures
13	Hitoshi TAMURA Senior Researcher, Marine Information Group	FY2019 Hydrographic Technology Encouragement Award	Japan Hydrographic Association (general incorporated foundation)	February 27, 2020	Development of a wave prediction system for ocean swells based on a coupled phase model

Active Commitment in International Meetings, Workshops, and Other Projects

In December 2015, the United Nations General Assembly officially designated November 5th, which has already been designated as Tsunami Prevention Day in Japan, as World Tsunami Awareness Day. Subsequently in 2016, the Goryo Hamaguchi International Award, an award granted by the Minister of Land, Infrastructure, Transport and Tourism, was inaugurated, to recognize those who have made significant accomplishments related to the prevention and mitigation of tsunami and other coastal disasters. On October 29, 2019, the award was given to two recipients: Dr. Tomoya Shibayama, professor at Waseda University and professor emeritus at Yokohama National University, and Dr. Ahmet Cevdet Yalciner, professor at Middle East Technical University (Turkey).

A prize awarding ceremony and commemorative lecture of the Hamaguchi Award (October 29, 2019, Tokyo)

In May 2019, PARI representatives attended Coastal Sediments 2019 held in Houston, Texas, U.S.A., which is an international conference on bottom sediment movement and topographic changes in coastal areas, to present their research findings on the medium-term topographic changes observed on back shores, and gather information on various research projects taking place overseas.

In addition, PARI hosted a seminar at the University of Transport and Communications (UTC) in Hanoi, Vietnam in November 2019, on life cycle management pertaining to marine structures. During the event, lectures were given on the electrolytic protection of concrete structures from corrosion, etc., and participants actively exchanged ideas and opinions on the topic.

Broad Research Exchange with Japanese and Overseas Research Institutes

To improve the quality and efficiency of research, we actively collaborated on research with domestic and overseas research institutes and signed a total of 39 research cooperation agreements with 13 Japanese and 26 overseas institutes as of FY 2019. Also during FY 2019, PARI extended the research cooperation agreement it had executed with the French Institute of Science and Technology for Transport, Development and Networks (IFSTTAR) in order to continue with the mutual technical cooperation between the parties in geotechnology and civil engineering.

Conclusion of Education and Research Collaboration Agreements

We signed agreements with national, public and private universities. Under these agreements, PARI researchers serve as grad-school professors or take other positions at the universities. Under the graduate school linking system, in which postgraduate students receive instructions at research institutions, we concluded collaboration agreements with 12 universities including the Tokyo Institute of Technology, Nagoya University, and Nagaoka University of Technology. In FY 2019, we dispatched 9 researchers as lecturers. We also dispatched a total of four researchers to universities which are not under the graduate school linking system, including the Nihon University.

Promotion of Administrative Support

Dispatching of Researchers to Disaster Sites

As record rainfall occurred on August 28, 2019 mainly affecting Northern Kyushu and caused damage to bulkheads on the coast around Shimonoseki Port in the Sanyo region, PARI dispatched four researchers, etc. (two of whom were PARI employees) to Shimonoseki Port, jointly with the Ports and Harbours Bureau, MLIT and the National Institute for Land and Infrastructure Management (Yokosuka), to investigate the details of the damage caused by the disaster.

In addition, the violent winds caused by Typhoon Faxai that passed over Japan on September 9, 2019 caused a ship to collide into Hama Road in Minami-Honmoku pier of Yokohama Port, and also the storm surge driven by the same typhoon caused damage to the bulkheads on the pier there, so PARI dispatched seven researchers to the site to investigate the damage to the bulkheads.

Furthermore, as Typhoon Hagibis made landfall on the Izu Peninsula on October 12, 2019, and the storm surge driven by this large and strong typhoon caused damage to the bulkheads in the Kanazawa area of Yokohama Port, PARI sent four of its researchers to the site for investigation.

Dispatching of Researchers to Various Technical Committees

We dispatched a total of 131 researchers to various technical committees organized by governments and other organizations to solve technical issues concerning the execution of port, coastal, and airport public works by national and municipal governments and local administrations. Including technical committees on improving ports, coasts and airports established by various institutions, a total of 316 researchers were dispatched by PARI, and actively tackled technical issues faced by governments and other organizations.

Dispatching of Lecturers to Training Courses for Domestic Engineers

Training courses for national and other public service engineers are held by NILIM. We actively participate from the planning stage and have dispatched a total of 34 researchers to 15 training courses as lecturers.

Providing Operational Support for Technical Standards for Ports, Airports, etc.

Regarding technical standards for port facilities, our researchers took part in technical committees set up by the Ports and Harbours Bureau of the Ministry of Land, Infrastructure, Transport and Tourism. Our researchers also gave lectures at NILIM, conferences, and seminars organized by other relevant organizations, and contributed to the spread of technical standards. Regarding airport facilities, our researchers participated in various investigative commissions in preparation for the smooth introduction and operation of technical standards for airport civil engineering facilities.

Support for Evaluation of New Technologies

In response to a request of the Ministry of Land, Infrastructure, Transport and Tourism (including regional development bureaus), PARI offered technical support by dispatching researchers to the New Technology Utilization Evaluation Conference established by each organization for evaluating the practicality and applicability of the technologies to be registered in the New Technology Information System (NETIS) in order to promote the application of useful new technologies.

July 2020

—Creating Technologies that Contribute to the World—

National Institute of Maritime, Port and Aviation Technology

Port and Airport Research Institute

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