August 2023 No.99
Japanese Infrastructure Newsletter

IDI QUARTERLY

Infrastructure Development Institute—JAPAN

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"Building National Resilience" ・ Introduction of Hydraulic Model Experimental Facilities Leading to "River Basin Disaster Resilience Measures"

～Hydraulics･Understanding of Sediment Transport Phenomena ～Seeing Is Believing～

1. Introduction

Japan is one of the most disaster-prone countries in the world, with natural disasters such as heavy rains, typhoons, floods, earthquakes, tsunamis, and volcanic eruptions. Therefore, measures for "Building National Resilience" with "Strength and Agility" are being promoted to protect people's lives and property. These measures will minimize damage to the economy and society and ensures a quick recovery in the event of a large-scale natural disaster.

In recent years, wind and flood damage due to climate change has become more severe and frequent, causing extensive damage in many areas. For this reason, "watershed flood control measures" are being advanced, in which the national government, local governments, private companies, residents, and all other parties concerned cooperate to promote flood control measures in the catchment areas, river areas, and flooded areas of river basins.

In order to implement measures for "Building National Land Resilience" and "River Basin Disaster Resilience", disaster prevention measures should be taken. Such measures include the construction of erosion control dams and sediment-retarding basins, river channel excavation/levee construction, and the installation of rainwater storage facilities. To adopt effective proactive disaster prevention measures, it is necessary to verify and forecast situations in the event of a natural disaster, and to conduct analysis and evaluation.

One of the solutions for verification and prediction is an evaluation method using hydraulic model experiments. Hydraulic model experiments make it possible to reproduce complex natural phenomena in a form that is complementary to hydraulic analysis and field observations and studies, which contribute to solving problems. This paper introduces our Tsukuba Research Center's hydraulic model test facilities and their technologies.

2. Outline

Our Tsukuba Research Center was established in 1984. It is one of the largest research facilities owned by a construction consulting firm in Japan. The center consists of an outdoor experimental field, an indoor experimental building, and an environmental analysis laboratory (Photo 1).

Photo 1: Outdoor experimental field and indoor experimental building

The outdoor experimental field has an area of 22,000 m² and can accommodate hydraulic model test equipment with a linear extension of up to 130 m. In addition, it has two water flow systems with a maximum water flow rate of 0.75 m³/s. Water used for hydraulic model experiments is returned to a low-set water tank through an on-site return channel for cyclic use. Our hydraulic model experimental facilities are classified into two types: permanent channels and channels to be tailored for each commissioned project. The permanent channels consist of two large, permanently-installed straight channels with a width of approximately 1.0 m and a length of approximately 30 m.

The indoor experimental building is a column-free space with an area of 1,890 m² and a maximum ceiling height of 10 m (Photo 2).

Photo 2: Inside of the indoor experimental building

The indoor experimental building is used for experiments on dam facilities, which require high measurement accuracy. It is also used for water supply and sewage experiments, which often use acrylic models that are easily affected by sunlight, as an indoor facility that enables experiments and tests without being affected by weather conditions. In addition, a liner channel with wave-making equipment is permanently installed in this building.

Pacific Consultants uses these indoor and outdoor facilities to carry out hydraulic model experiments on rivers, erosion control, dams, sewage systems, coasts and harbors, etc. On top of that, we use them for hydraulic analysis in order to conduct consulting activities to solve challenges on-site.

3. Detailed Description

Hydraulic model experiments are a method of obtaining hydraulic phenomena similar to those of real objects by creating a model according to the law of similarity and flowing water through the model. Complexity of natural phenomena occurring in rivers and through erosion control makes it difficult to predict these phenomena. Hydraulic model experiments can represent complex hydraulic phenomena and riverbed geometries in three dimensions, making them easier to understand visually (Photo 3). In addition, various conditions for planning and disasters can be set arbitrarily, so that the hydraulic phenomena to be verified or predicted can be created. Therefore, this makes it possible to study effective proactive risk reduction measures against natural disasters.

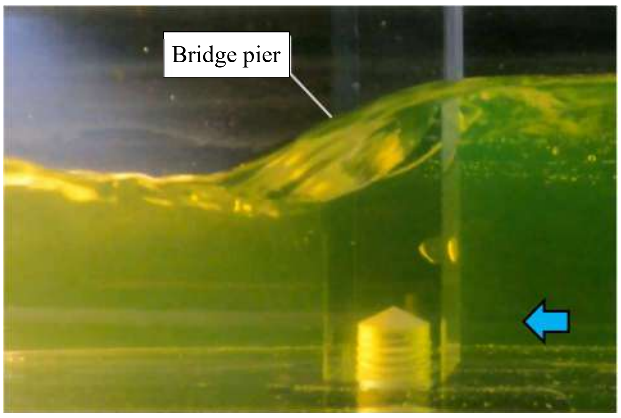

Photo 3: Hydraulic phenomena around a bridge pier

On the other hand, hydraulic analytical models are used as a method to verify and predict conditions during natural disasters.

Compared to hydraulic analytical models, hydraulic model experiments are more accurate in reproducing energy loss around channels with complex geometries. Hydraulic model experiments are considered to be more effective than hydraulic analytical models in expressing the deformation of riverbed shapes and the resistance they receive depending on water depth. On the other hand, hydraulic model experiments also have their own applicable conditions, and in some cases, hydraulic analytical models provide a more accurate reproduction than hydraulic model experiments. Therefore, it is necessary to understand the characteristics of hydraulic model experiments and hydraulic analytical models, and to consider the use of each method or combination of both methods based on the engineer's judgment.

4. Scope of application

The scale of the model is an important factor in the application conditions of hydraulic model experiments. The scale of the model is determined based on a comprehensive evaluation of the purpose of the experiment, the type of hydraulic phenomena, the scope of the experiment, the area and water flow capacity of the experimental facility, and the cost and duration allowed for the experiment.

For example, with respect to the purpose of the experiment and the type of hydraulic phenomena, in the case of experiments on river channels and erosion control, etc., it is necessary for ensuring hydraulic adequacy that the model should be configured with a water depth of 3 cm or more in the critical section and in a turbulent basin so that viscous effects can be ignored.

The scale of hydraulic model experiments is transformed according to the Froude and Reynolds similarity laws. In the case of the Froude similarity law, the unit of length is the first power of the scale and the unit of time is the 0.5th power of the scale. If the full-scale hydraulic volume has 10,000 m^3/s flow rate, 3.0 m depth, 10 km extension, 1 km channel width, and 1 day of experimentation time, converted at 1/100 of the model scale according to the Froude similarity law, the following results would be obtained: 0.1 m^3/s flow rate, 3 cm depth, 100 m extension, 10 m channel width, and 2.4 hours of experimentation time.

The larger the scale of the model, the closer it is to the real situation and the better the reproducibility of hydraulic phenomena. However, the scale should be set after ensuring hydraulic adequacy while taking into consideration the area of the experimental facility, the water flow capacity, and the cost and duration allowed for the experiment. Our experimental facility has one of the largest water flow capacities in Japan and the largest area for experimental facilities, which enables us to set a large model scale and perform hydraulic model experiments that ensure hydraulic adequacy.

In the case of large rivers with a river width of several kilometers or shallow water depths, it is difficult to set a model scale that ensures hydraulic adequacy. In such cases, we use distorted models with different horizontal and vertical model scales, or extracted models with the focus area cut out, in an effort to verify hydraulic phenomena.

5. Anticipated Results

In the study using hydraulic model experiments, experiments are conducted on draft plans for countermeasure facilities, and hydraulic phenomena obtained from the experiments are evaluated to study improvement plans for facilities with higher countermeasure effects and so forth. Then, hydraulic model experiments can be carried out again for the proposed facility improvement plans to determine proactive disaster prevention measures that are considered optimal.

Hydraulic model test studies typically cost several million to tens of millions of yen. Since the price of a hydraulic model experiment is low compared to the cost of facility construction, it is advantageous to perform such experiments prior to facility construction so that the best plan can be considered economically and effectively. In short, hydraulic model experiments prior to facility construction can lead to cost-effective, proactive disaster risk management.

6. Record of implementation

The national government, local governments, private companies, residents, and all other stakeholders in river basins are working together to study measures for “Building National Resilience” and “River Basin Disaster Resilience”. These measures include construction of erosion and sediment control dams, flood control areas, driftwood traps, retarding basins, river channel alignment to secure flow capacity, levee structures, pier scour protection, etc. This chapter describes the measures to be taken to prevent scouring of bridge piers and other related structures. This chapter also presents representative examples of hydraulic model experiments related to these measures.

(1) River improvement

Using hydraulic model experiments, we are examining various factors such as overflow levees, energy dissipator works attached to retarding basins, and measures against bridge pier scouring. We are also studying river channel alignment to ensure flow capacity. As representative examples, we will introduce hydraulic model experiments related to retarding basin and bridge pier scouring countermeasures.

Retarding basins are facilities that store floodwaters and lower downstream channel water levels to reduce the risk of flooding. Around the overflow levee of the retarding basin, the depth and velocity of water in the channel vary depending on the channel flow, channel topography, vegetation in the channel, etc. The drag force and energy loss that the flow receives from the overflow levee change according to these factors, and the overflow rate from the river channel to the retarding basin will be determined (Figure 1).

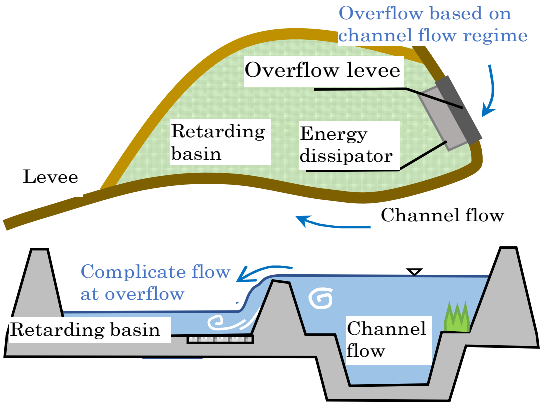

Figure 1: Flow regime around the overflow levee of the retarding basin

The impacts on the flow regime caused by changes in energy loss and other factors are difficult to evaluate using only hydraulic analysis models. Therefore, hydraulic model experiments are used in the study of overflow levees and energy dissipators attached to the water basin to ensure that the appropriate overflow can be secured in accordance with the river channel flow rate (Photo 4).

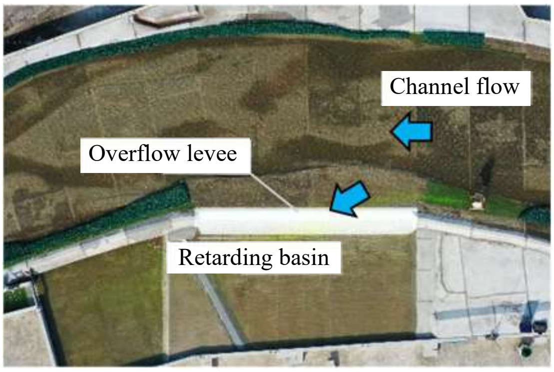

Photo 4: Hydraulic model experiment on retarding basin

In recent years, road bridges and railroad bridges have been damaged by floods, delaying the recovery of local communities and economic activities even after the floods. Damage to bridge piers is often caused by scouring of the riverbed near bridge pier foundations during floods. Therefore, there is a need for bridge pier scour countermeasures to control riverbed scour during floods and to protect bridge pier foundations.

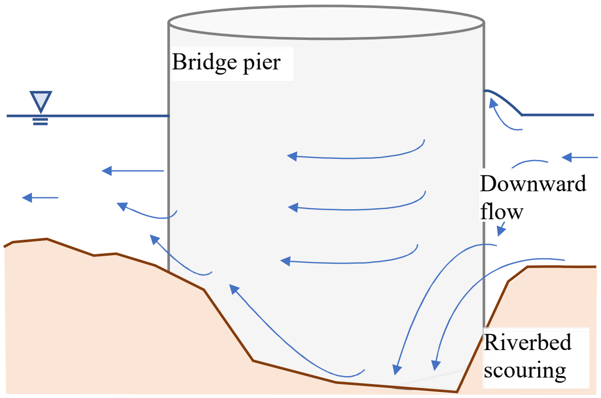

Figure 2: Flow regime and riverbed fluctuations around bridge piers

Riverbed scour around bridge piers is caused by the complex flows around the bridge piers (Figure 2). In front of the bridge piers, the flow impinges on the bridge piers, resulting in a non-hydrostatic distribution and downstream flow. Secondary flows are generated at the sides of the bridge piers due to condensing and downstream flows. Although riverbed scour occurs depending on these complex flows, it is difficult to reproduce and predict scour around bridge piers using general-purpose riverbed fluctuation analysis models in practice. Therefore, hydraulic model experiments are being used to assess scour vulnerability in complex flow fields and around bridge piers, and to study measures against bridge pier scour (Photo 5).

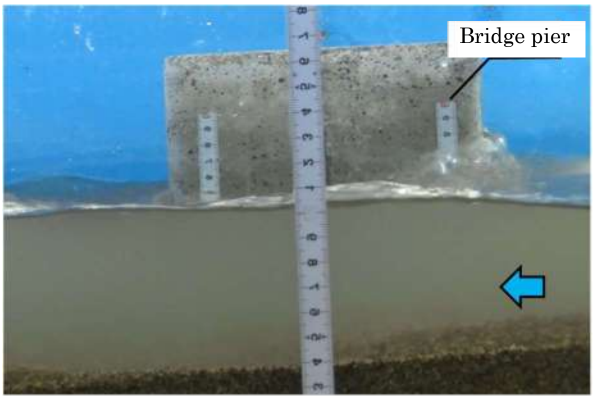

Photo 5: Hydraulic model experiment on bridge pier scouring

(2) Field of Erosion Control

In the field of erosion control, it is necessary to construct facilities such as erosion control dams, driftwood traps, and sediment-retarding basins to capture sediment and driftwood that flow out of mountainous areas during rainfall events. For this reason, hydraulic model experiments on erosion control model sediment and driftwood in addition to water, to confirm the effectiveness of soil and driftwood trapping facilities, etc. for storing soil and driftwood (Photo 6).

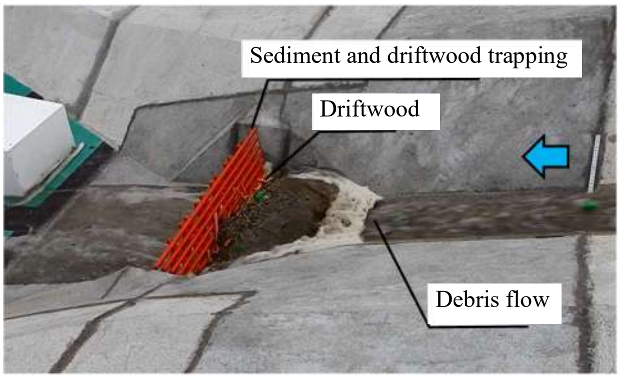

Photo 6: Hydraulic model experiment on measures against debris flow

7. Conclusion

Hydraulic model experiments are one effective means of clarifying hydraulic phenomena when implementing “Building National Resilience” and “River Basin Disaster Resilience Measures”, including facility development and comprehensive countermeasure studies. This experimental method can reproduce complex flows, riverbed fluctuations, etc., under a variety of assumed conditions, and can efficiently and cost-effectively study the best solution.

In addition, there is a need for more advanced hydraulic analysis models to cope with the increasing severity and frequency of water-related disasters due to climate change. For this purpose, the reliability of hydraulic analysis models can be improved by refining them based on hydraulic phenomena obtained from hydraulic model experiments and field observations, and by verifying their accuracy by comparing results obtained from hydraulic analysis with those obtained from measurements.

Tsukuba Research Center will continue to improve its technological capabilities and promote technological development. It will also utilize hydraulic model experiments and other hydraulic analysis models to solve problems related to various rivers, erosion control, dams, sewage systems, coasts, ports, and harbors.

8. Conctact Information

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"Efforts Toward Coastal Conservation"

～Introduction of Analysis and Monitoring Techniques～

1. Introduction

Owing to the fact that Japan is surrounded by the sea on all sides, flood protection measures for backlands through the development of coastal protection facilities have been promoted, learning from the damage caused by tsunamis and typhoons in the past. However, the situation surrounding coasts is now undergoing significant changes. This includes changes in the way coastal protection facilities are being developed in response to the 2011 Great East Japan Earthquake, predicted rises in tide levels, and increases in waves and storm surges due to recent climate change. In this report, we introduce the efforts of our company, Pacific Consultants, Co., Ltd. to address these challenges.

2. Review of assumptions for tsunami inundation and heights of seawalls

The Great East Japan Earthquake prompted a review of tsunami inundation assumptions and seawall heights, focusing on the Tohoku Region but including all of Japan. The following describes our efforts to revise tsunami inundation assumptions and sea dike heights in the aftermath of the Great East Japan Earthquake.

First, it is necessary to know the size of the tsunami that hit each area and the extent of the damage, in order to recover from the disaster. However, there were not enough observation stations along the coasts, and observation equipment was damaged or missing in the coastal areas where the tsunami damage was severe. Immediately after the Great East Japan Earthquake, Pacific Consultants participated in a disaster survey conducted by coastal municipalities, and a tsunami trace survey organized by the Japan Society of Civil Engineers (JSCE) and universities. Our these activities contributed to quickly grasping the situation of background inundation as well as damage to coastal protection facilities that could not be covered by coastal observation points. The results of the tsunami trace survey have been published in the "Tsunami Trace Database in Japan" at Tohoku University, and are being used as the basis for tsunami inundation assumptions, group relocation to higher ground, and review of seawall heights.

The tsunami trace data can provide information on inundation results expressed in two dimensions. However, when planning community development and protective facilities, it is necessary to reflect the effects of the following on the inundation situation: raising seawalls and the ground level, as well as other improvements. Therefore, it is effective to have tsunami simulations that can reproduce faulting and sea-level changes. Immediately after the Great East Japan Earthquake, we collaborated with Tohoku University to propose a fault model (the Tohoku University model) that can reproduce tsunami traces well. We were also involved in tsunami inundation estimates for coastal municipalities, which contributed to rapid reconstruction and urban planning (see Figure 1 and Figure 2).

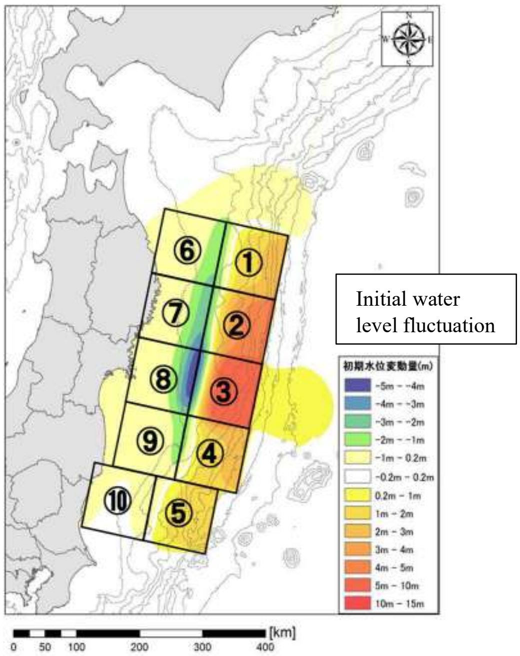

Figure 1: Distribution of initial water level fluctuation based on the created fault model
(The boxes and circled numbers in the figure indicate fault segments.)

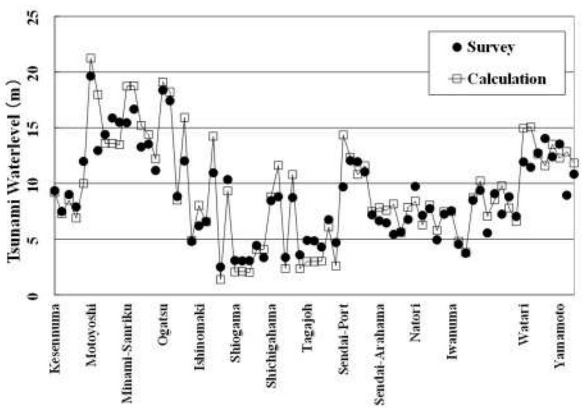

Figure 2: Comparison of trace values and reproduction calculation results

3. Review of storm surges and waves in light of climate change and study of their impact on beaches

The Intergovernmental Panel on Climate Change (IPCC) and other organizations have begun to indicate specific future impacts of climate change, with the recent progress in forecasting technologies for meteorological and oceanographic phenomena. In Japan, it has become mandatory to study coastal protection levels and revise the basic coastal protection plan by 2025, based on the analysis of past meteorological and oceanographic data as well as the long-term changes in external forces due to climate change.

On the other hand, the following practical issue has remained to be addressed: while there are items in the IPCC's report that provide specific numerical projections of temperature and sea level rises, the rate of change in the extent of storm surges and waves, which is an important element of coastal disaster prevention, has not been presented in detail, although the possibility of their increases has been pointed out.

Pacific Consultants is involved in identifying and predicting trends regarding changes in storm surges and waves associated with climate change, in relation to external forces of the climate in the future, through joint research with universities, ordered by the national and local governments. This study simulates storm surges and waves under the present and future climate. The results of these studies will be reflected in the basic coastal protection plan which takes the effects of climate change into account.

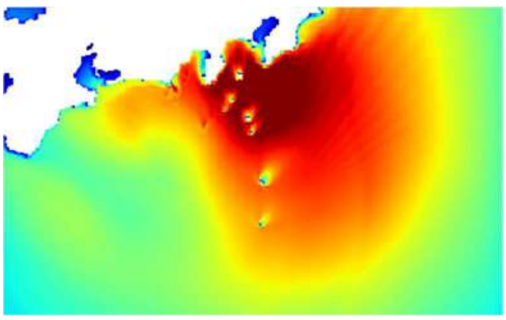

Figure 3: Example of wave simulation
(Typhoon No.19 in 2019)

In addition, there is concern that the level of protection in the coastal backlands will decline as the risk of beach loss increases because of sea level rises due to the impacts of climate change as well as long-term changes in external forces. Given the future prediction and impact assessment of the shapes of beaches caused by climate change, beach protection is extremely important for land conservation in Japan.

On the other hand, many beach deformation models currently used to study the effects of climate change predict shoreline position or longitudinal topography of beaches with regard to representative wave parameters. This makes it difficult to track the external forces that change due to climate change impacts, which have long-term, continuous trends. Therefore, we are studying the long-term effects of climate change on beaches and their applications through joint research with universities. In this research, we use XBeach (eXtreme Beach behavior), which can explain wave fields, current fields, and sand drift, as well as the effects they have on each other, and can conduct long-term integration after introducing a morphological change coefficient (see Figures 4 and 5).

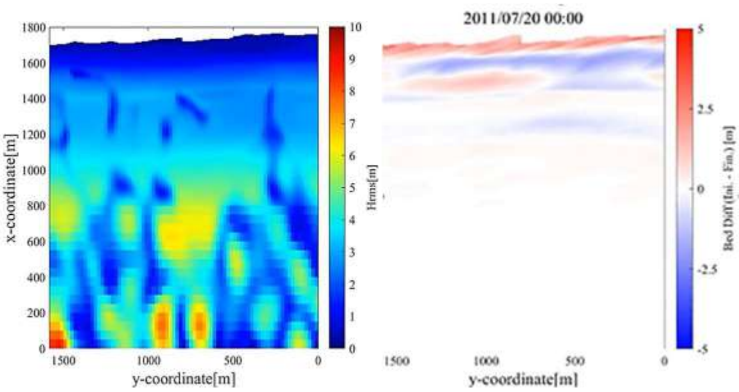

Figure 4: Wave height distribution and amount of topographic change relative to initial topography at the time of high disturbance (XBeach)

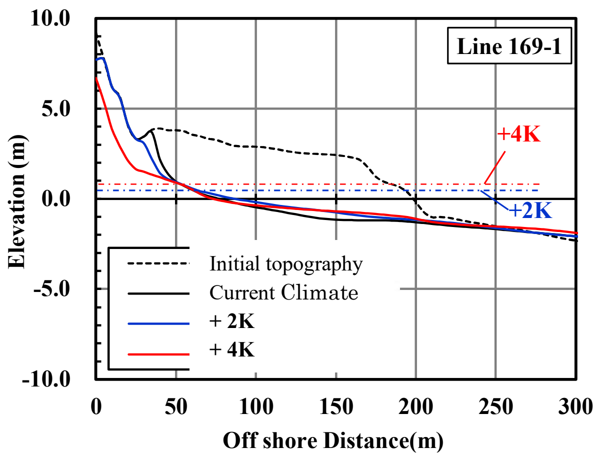

Figure 5: Example of projected results of future topographic change under current and future climate (2°C and 4°C increase)

4. Coastal zone monitoring using new technologies

While the situation surrounding coasts has been changing, we believe that monitoring situations in coastal areas, including sandy beaches, is an enormously important initiative. With this in mind, we have decided to accelerate our project development utilizing the latest spatial information technology not only in the coastal field of research, but also in the construction field in general. Specifically, from the viewpoints of land, sea, air, and space, we aim to capture phenomena by using all kinds of means, and to utilize the data. To achieve these objectives, we are working to advance our analysis and utilization techniques for images, point cloud data, and other data obtained through data acquisition technologies.

Among these, in the coastal sector, technologies for monitoring coastal areas include wide-area imaging using powered fixed-winged UAVs capable of traveling hundreds of kilometers. There are also technologies such as for laser measurement and imaging of land-to-sea areas, using optical and SAR satellites. We expect that the data acquired through these techniques will provide us with new insights.

In particular, SAR satellites, which use microwaves for observation of topography and structures, can make observations, regardless of cloud cover, and both during the day or night. In October 2021, we agreed to form a business alliance with Synspective Inc., which provides small SAR satellite constellations and satellite data solutions. We will plan to make proposals for coastal protection and disaster prevention to monitor coastal areas and use acquired data by making use of satellite data analysis technologies from Synspective Inc.

The company's small SAR satellite, StriX, is capable of observation with 1 to 3 m resolution in the X-band. In addition to deciphering topography such as coastlines (Figure 6), vessels and structures, analysis using data from multiple periods enables detailed observation of coastal areas, including measurement of ground and structure displacement, detection of flooded areas, and observation of the extent of marine drift, pyroclastic material, and petroleum dispersion (Figure 7).

Figure 6: StriX-α image (1m resolution)

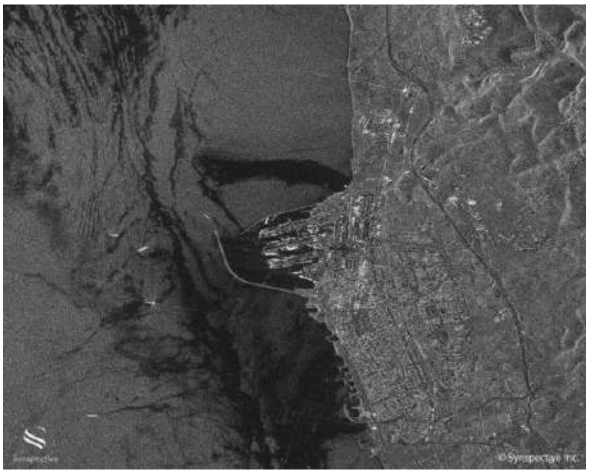

Figure 7: StriX-α image (3m resolution)

In this way, we will aim to create a safe and secure coastal zone while continuing to address various issues by utilizing the latest technologies and responding to changes in the natural and social conditions surrounding coasts.

5. Contact Information

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About “Japan Construction International Award”

The Ministry of Land, Infrastructure, Transport and Tourism established the “Japan Construction International Award (Honored by the Minister of Land, Infrastructure, Transport and Tourism)” in 2017, and it has become a global showcase of “Quality Infrastructure,” which commends (1) overseas construction projects which demonstrate Japan’s strengths, (2) small and medium-sized construction companies which play active and leading roles overseas, and (3) overseas pioneering Activities by Japanses companies, universities and academic institutions.

Through this award, the Ministry of Land, Infrastructure, Transport and Tourism aims to promote global understanding of the Japanese companies’ competitiveness and expect more projects to be carried out by Japanese companies.

The 6th Japan Construction International Award ceremony was held on June 20, 2023.
For the 6th Japan Construction International Award,
5 projects were awarded for the “Construction Project Category,”
2 companies were awarded for the “Small and Midium-sized Enterprises Category,”
and 2 projects were awarded for the “Pioneering Activity Category.”

Please check about the 6th Japan Construction International Award from the link below.
https://www.mlit.go.jp/JCIA/en/award/6/

You can also download the 6th Japan Construction International Award brochure from the link below.
https://www.mlit.go.jp/JCIA/en/content/Japacon_brochure_6th.pdf

About IDI and IDI-quarterly

Infrastructure Development Institute-Japan (IDI) is a general incorporated association operating under the guidance of Ministry of Land, Infrastructure, Transport and Tourism of Japanese Government.

IDI provides consulting services to facilitate international assistance to developing countries, to promote international exchange of information and human resources, and to support globalization of project implementation systems targeting both developed and developing countries in the field of infrastructure.

IDI has been publishing a free quarterly journal called "IDI Quarterly" since1996 to introduce information related to public works and construction technologies developed in Japan, to foreign countries. We have distributed the journal to administration officials in more than 90 countries around the world via e-mail.

It will be highly appreciated if you could send us your opinions, impressions, etc. regarding the articles. We also welcome your specific requests regrading technologies you would like to see on following Quarterly issues.