Technical Articles
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IMPORTANT POINTS IN MID- AND LONG-TERM POLICY FOR PORTS ‘PORT 2030’

by

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Keywords: maritime transport network, cruise hub, carbon free ports, al terminal, CIM (Construction Information Management/Modelling)

Mots-clés: réseau de transport maritime, hub de croisière, ports sans carbone, terminal intelligent, CIM (Construction Information Management/Modélisation)

1 INTRODUCTION

Basic Direction of Mid- and Long-term Policy for Ports ‘PORT 2030’ and Specific Measures

The world's economic environment is drastically changing. In the manufacturing industry, many private companies have established a system of international divisions of labor beyond national borders and implemented advanced supply chain management. In addition, the development of ICT (Information and Communication Technology) is accelerating the digitisation of various economic and logistic activities; analysing and applying ‘Big Data’ allows it to create new economic value in distribution markets worldwide.

As a nation entirely surrounded by the sea, ports and harbours play important roles as social assets that support economic growth and the livelihood of the people. It is therefore vital to continue evolving these ports and harbours by introducing up-to-the-minute innovative technology so that Japanese companies can maintain their international competitiveness amid enhanced economic efficiency and intensifying competition due to ICT development.

Under these circumstances, we embarked on a revision of the mid- and long-term policy for ports, ‘PORT 2030’, to clarify the role that ports will play and the direction in which to promote port policy. Focusing on the future around 2030, we released the final version in July 2018 after reviewing the policy for over two years.

‘PORT 2030’ targets three roles that Japanese ports should play in 2030: (1) ports that connect and open the country to the world (‘Connected Ports’); (2) spaces that create new value (‘Premium Ports’); and (3) platforms that lead the fourth industrial revolution (‘Smart Ports’) in light of changes in the circumstances surrounding Japanese ports and the problems they face.

First, the two aspects of ‘networking’ and ‘creation of space’ were already mentioned in the previous vision. As they remain important roles, the new policy also keeps them as targets to achieve with a new approach under the concepts ‘Connected Ports’ and ‘Premium Ports’. In addition, the new policy delivers a new concept that takes advantage of innovative technology, including ICT, which continues to evolve at breakneck speed, connecting not only physical space but also information space and leading the fourth industrial revolution, ‘Smart Ports’.

Based on those envisioned three roles, the functions required of ports in the 2030s and the specific measures necessary to realise them are summarised in the following eight themes.
2 CREATING A MARINE TRANSPORT NETWORK THAT SUPPORTS THE GLOBAL VALUE CHAIN

We will introduce structural and non-structural measures to strengthen direct services from major domestic ports while positioning shuttle routes to accelerate growth of the Southeast Asian region as strategically important routes. The aim is to shorten the lead time of international cargo transport and improve the locational competitiveness of Japanese private companies. Taking in cargoes from the Asian region supports the international container strategic port policy that aims to maintain and expand port calls of vessels on long-haul core routes connecting Japan to major markets in Europe, the United States, and the rest of the world. It is our goal to gather cargoes not only from various parts of Japan but also from Asian countries and the rest of the world by forming a number of logistics hubs capable of providing new added value.

This value encompasses advanced distributive processing, quarantine, and dispatching as well as export of recycled parts and cross-border repair services. The strategy takes advantage of the advanced technology of Japan's manufacturing industry to create new value, earn foreign currency, and promote creation of jobs in the port hinterland. Furthermore, we will encourage joint procurement and transport of small-lot cargoes among companies to boost exports of Japan-made agricultural, forestry and fisheries products that have recently attracted a lot of attention, mainly in the East Asian region. In addition, in order to respond flexibly to the ever-growing complexity of enterprise supply-chain management, we will strengthen international ferry and RORO routes and container shuttle routes centering on the Asian region and aim to form a multi-layered route network comprising a variety of speed zones.

3 ESTABLISHING A DOMESTIC LOGISTICS SYSTEM THAT CREATES SUSTAINABLE NEW VALUE

Since flexible capability is required for domestic ferry and RORO routes, such as the ability of allowing vessels to dock at a quay wall confirmed to be safe in the event of a disaster, it is necessary to promote standard integration or standardisation of quay walls through cooperation with shipping companies. To this end, the Japanese government will collaborate with shipping companies willing to carry out reform, administrators of ports as ports of call, and other cooperating parties to set up a Unit Load Productivity Reform Council (working title). The council will study how to significantly upgrade equipment of both vessels and ports and their operating systems to enhancing transport productivity.

In addition, we will locate international container terminals close to domestic unit load terminals by reorganising wharves and realise seamless connections between ports and their hinterland roads, as well as develop and improve quay walls able to receive larger vessels to promote the gathering of cargoes to strategic international container ports. To ensure better safety and efficiency of marine transport, we will promote the introduction of automatic vessel navigation and navigation assistance technology that applies artificial intelligence (AI) and develop and spread the ‘next-generation high-standard unit load terminal’.

Figure 1: Marine transport network that supports the global value chain
This terminal concept features various capabilities including high-standard cargo-handling machinery and embarkation/disembarkation facilities, an automatic berthing/leaving system coordinated with automatically navigated vessels, automatic drayage in the terminal compound at domestic terminals, and an efficient charge settling system. We also plan to obtain the ability to identify the locations of trucks and chassis with GPS and other ICT techniques, optimising transport operations. In addition, since it is necessary to reinforce the capability to export and ship agricultural, forestry and fisheries products, we will boost quality control by introducing a reefer container-temperature monitoring system to ensure the quality of agricultural, forestry and fisheries products.

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4 THE ARCHIPELAGO AS A CRUISE HUB

We will take all necessary steps to increase the number of cruise services that originate in Japan and form a ‘Northeastern Asian cruise hub’ in Japan. This will include establishing international cruise bases through public-private partnerships and promote ‘fly and cruise’ programmes. Especially to attract foreign cruise tourists as repeater visitors, the plan involves employing IoT and other methods to collect and analyse detailed data on their degree of satisfaction and other relevant determining factors for the provision of high quality services.

Additional measures in terminal buildings cover upgrading convenience for users, such as by providing free Wi-Fi services and multi-lingual guidance. Furthermore, the vision incorporates advocating coordination with domestic and international ferry services that have recently been refining their own product to capture a greater share of not only foreign but also Japanese cruise tourists. We will also be aiming to establish wide-area traveling routes, including islands, through seamless connection and cooperation with railroads, aircraft, ports and harbours.
Recently, more distribution and industrial functions have been shifting offshore in response to the increasing size of vessels, and the vacant space left behind in inner harbour areas has created a need to make effective use of this valuable land. In this respect, our vision involves revitalising ports by encouraging new approaches to redevelopment using private funds. To produce bustle in ports and provide opportunities for exchanges between foreign tourists and Japanese citizens, we will advance the establishment of attractive venues by exploring and refining various sightseeing resources such as culture and history, beach sports experiences, landscaping, the natural environment, fish dishes and the night-time economy including night views of factories and illuminated waterfronts.

**5  SHAPING SPACES TO CREATE BRAND VALUE**

**6  ESTABLISHING BASES TO RECEIVE AND SUPPLY NEW RESOURCES AND ENERGY**

We will work with other ministries and agencies to promote renewal, improvement and strengthening of transport infrastructure to boost the competitive force of petroleum-related industries in waterfront zones and the basic materials industry that supports local economies. For instance, vacant space created by business consolidation in the petroleum-related industry will present a valuable opportunity to introduce new businesses. In this respect, we may invite energy-related businesses compatible with the waterfront zone, such as businesses dealing with LNG or hydrogen. In addition, we will use ICT to promote joint transport between companies in response to the increasing size of vessels and diversification of procurement sources in terms of shipping conventional resources such as coal. Since it is crucial to ensure a stable and inexpensive supply of resources and energies to Japan and maintain Japanese maritime interests, we will help diversify resources and energy by promoting wind-power generation off Japanese ports and maintaining bases for supplying hydrogen or biomass fuel.
7 GREENING OF PORT AND DISTRIBUTION ACTIVITIES

To help cope with the world's environmental problems, we are aiming to realise ‘carbon-free ports’ ahead of other ports in the world by taking ‘measures focused on CO₂ emission sources’. Such measures include setting up offshore wind-power generation, advocating low-carbon in transport machinery such as vessels, cargo-handling machines and trucks, and introducing onshore power-supply equipment. Additional initiatives are promoting ‘measures focused on CO₂-absorbing sources’, such as utilising the blue carbon ecosystem such as seagrass beds nurtured with effective use of industrial byproducts such as steel slag. Furthermore, taking advantage of Japan’s position as the world’s largest LNG importer and having many LNG bases right across the country, we will establish LNG bunkering hubs to make ports more environmentally friendly. Moreover, to maintain the environment and safety of ports and routes, preferential treatment will be given to ports that encourage port calls by environmentally conscious vessels – such ports are currently increasing in number. Other actions to promote include widening channels and establishing emergency mooring berths.

8 USING ICT TO DEVELOP SMARTER AND STRONGER PORTS

8.1 Digitisation of Ports and Cooperation with other Information Infrastructures

Part of ‘PORT 2030’ is to establish a ‘port-related data cooperation platform’, in which a variety of information related to ports, such as port and trading procedures, is electronically linked. Specifically,
we are supporting the development of an environment where all port information and trading procedures are electronically handled on this infrastructure, or ‘full digitisation of ports’. Connecting this infrastructure to information platforms of overseas ports and different businesses will promote links containing information on agricultural, forestry, and fisheries product cargoes and tourist information, with the aim of realising ‘cyber ports’ that can maximise convenience and productivity. When this system is put in place, it will be possible to create new information-based businesses and services in a variety of fields with port information as their core. Examples include international trade, tourist promotion, effective use of port facilities and disaster prevention in waterfronts.

8.2 Improvement of Terminal Productivity

To enhance terminal productivity and improve the working environment, we will combine AI, IoT and automation technology to optimise container storage plans and swift load-in and load-out of cargoes, thereby creating an AI terminal featuring the world’s highest class of productivity. For example, when a terminal is operating, AI will automatically predict appropriate terminal storage locations that minimise container storage and retrieval based on big data such as congestion information. Feeding the AI will be IoT-accumulated positional information on container vehicles, cargo-handling equipment and vessels that carry the cargo. Once a storage location is determined, AI will estimate the flow in which, after the gate crane picks up the container in the load chassis line, the automated gate crane will transport and store the container at a predetermined location. In future, we will actively introduce such innovative ICT and focus on realising the ultimate model of an ‘AI terminal’ that can reduce the time for container load-in/out procedures and CY cut-off days to almost zero while making the most of the information obtained from the above-mentioned infrastructure. The ultimate goal is to turn this technology and infrastructure development into a package and actively export it to overseas ports.

8.3 Response to Disasters

Preparedness against disasters is required of ports since gigantic disasters, such as the Nankai Trough Earthquake, a major inland earthquake in Tokyo, and other major wide-area disasters caused by earthquakes and tsunami are expected to strike Japan at any time. We will promote seismic retrofitting of quay walls and harbour roads to support quick restoration and rehabilitation of affected areas through sure distribution of materials immediately after a major disaster occurs. To maintain the safety and security of citizens, workers and travelers in ports, harbours and their hinterlands, the plan includes taking preventive actions for disaster mitigation such as those against flooding and liquefaction, and actively advocating for preparation of hazard maps and provision of disaster management education and disaster drills to enable quick evacuation. Furthermore, we will be reinforcing the collaborative and cooperative system among national and local organisations including the national government, port administrators, local governments, private companies and port cooperative organisations according to the port business continuity plan (Port BCP). Also to be established is a disaster-information provision system that can swiftly provide evacuation guidance and damage information to further reinforce the system.

When heavy rainfall occurred in July 2018 and a major earthquake struck the eastern part of Iburi, Hokkaido, in September 2018, remote islands and some coastal areas were isolated due to the severance of land transport routes. Commercial vessels, such as large dredger-cum-oil recovery vessels
and marine environment maintenance vessels, played an important role in supporting those isolated areas. Help included transporting emergency supplies by the marine route, supporting residents’ movements, and supporting daily activities including water supply for bathing and washing. Considering this, it is important to understand existing facilities of ports and how they are used in normal times and strengthen the cooperative relationship among relevant parties in advance so that smooth transport will be supported in the event of a disaster. We also assume port service vessels will play an important role in livelihood support and will therefore maintain the necessary functions and performance of those vessels.

At the time of the Great East Japan Earthquake, the tsunami warning was eventually lifted 30 hours after the disaster. Consequently, it took a lot of time to enter the afflicted areas. To ensure a swift response to future requests for transport of emergency supplies immediately after a similar disaster, we will establish a system that allows early detection of damage using advanced sensing techniques. Drones using IoT and other technology will form a key part of such a system because they reach places beyond areas that humans can directly access during tsunami warnings and enable the rapid shift to restoration and rehabilitation activities. Also in the plan is a system that allows integration and analysis of collected information and swift clarification of damage conditions, availability of infrastructure, such as ports and roads, and alternative route information, making it easier to assess the ability to accept support from the sea or flexibly organise wide-area alternative transport.

To cope with a future labour shortage, as well as improve productivity and safety in port construction, we are actively promoting the use of CIM (Construction Information Modelling/Management), which uses 3-D data digitised throughout the entire construction production process, such as surveying and

![Diagram](image)

**Figure 9: Clarification of damage conditions using ICT**

### 9 UPGRADING PORT CONSTRUCTION AND MAINTENANCE TECHNOLOGY AND SPREADING IT OVERSEAS

![Diagram](image)

**Figure 10: Improving maintenance efficiency using IoT**
measurement. Also being advanced is the progress of ‘i-Construction’, which incorporates proactive introduction of advanced technology such as multi-beams, underwater sonar and AR (Augmented Reality) and efficiency improvements to inspection services by employing IoT and robots, as well as boosting productivity in maintenance services. Three-dimensional conversion of the entire process will not only facilitate understanding of space occupied by infrastructure but also, for example, help young engineers carry out difficult work inspections as veteran inspectors do with the help of AR.

In addition, we will prepare guidelines for sharing outcomes that have been obtained in pilot projects on port technology. These projects have been conducted by the national government together with port administrators and private businesses in order to apply new technology to fields related to port maintenance. In addition, to help port-related businesses operate outside Japan, we will promote international standardisation of technical standards and compile Japan's advanced port construction, maintenance and operation technology into an ICT-based package for export overseas.

10 CONCLUSION

Ports are crucial distribution and production infrastructure that underpin a variety of industrial activities and the people’s livelihoods. At the same time, they serve as places where people from various places gather and exchange information. The Ports and Harbours Bureau of the Ministry of Land, Infrastructure, Transport and Tourism is determined to carry out specific measures according to ‘PORT 2030’, the government's mid- and long-term policy for ports revised for the first time in about 20 years. We are committed to taking a wide range of actions to help Japanese ports and harbors continue to provide the motive power to grow Japan's economy and society in the future.

SUMMARY

In July 2018, ‘PORT 2030’, the long-term policy for ports in Japan, was announced by the Ports and Harbours Bureau of the Ministry of Transport. This policy describes the future role of Japanese ports in the 2030s.

In addition to the basic function as hubs of maritime logistics and space where industries and people gather, this policy stressed the importance of utilising ICT to further port development. Eight main themes that will be promoted by the 2030s, were set forth including ‘Construction of Marine Transportation Network Supporting Global Value Chain’, ‘Space Formation Creating Brand Value’ and ‘Smartisation and Toughening of Ports Utilising Information and Communication Technology’.

The Ports and Harbours Bureau will promote measures based on ‘PORT 2030’ in order for Japanese ports to be the driving force of Japan’s economy and society.

RESUME


En plus des fonctions essentielles de plateforme logistique maritime et de lieu d’échange entre les industries et les populations, cette politique souligne l’importance de l’utilisation des nouvelles technologies de l’information (TIC) dans la promotion du développement des ports. Huit thèmes principaux qui seront importants dans les années 2030 ont été définis, notamment «Construction d’un réseau de transport maritime au service de la chaîne mondiale de valeur», « Création d’une valeur de marque par l’espace» et «Ports Intelligents et mise à profit des technologies de l’information et de la communication».

Le Bureau des ports soutiendra les mesures fondées sur « PORT 2030 » afin que les ports japonais soient le moteur de l’économie et de la société japonaises.
**ZUSAMMENFASSUNG**


Zusätzlich zu der Basisfunktion als Knotenpunkte für maritime Logistik und Lagerflächen, an denen Industrie und Menschen zusammenkommen, betonte diese Strategie die Bedeutung der Nutzung von IKT (Informations- und Kommunikationstechnik) für die Weiterentwicklung der Häfen. Acht Hauptthemen, die bis 2030 vorangebracht werden sollen, wurden dargelegt, u. a.: „Aufbau eines maritimen Transport-Netzwerks zur Unterstützung der globalen Wertschöpfungskette“, „Raumbildung zur Schaffung eines Markenwerts“, „Smartisation und Stärkung der Häfen durch die Nutzung von Informations- und Kommunikationstechnik“.

Die Hafenverwaltung wird Maßnahmen, die auf ‘PORT 2030’ basieren, fördern, damit japanische Häfen die treibende Kraft für Japans Wirtschaft und Gesellschaft werden.

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**RESUMEN**

En julio de 2018, ‘PUERTO 2030’, la política de largo plazo para los puertos en Japón, fue presentada por la Oficina de Puertos del Ministerio de Transportes. Esta política describe el papel a futuro de los puertos japoneses para la década de 2030.

Adicionalmente a su función principal como nodo de la logística marítima y espacio de intercambio para empresas y personas, esta política incide en la importancia en la utilización de tecnologías de información y comunicaciones dentro de los desarrollos portuarios a futuro. Se fomentarán ocho líneas principales de trabajo hasta la década de 2030, incluyendo la ‘Construcción de una red de transporte marítimo que apoye la generación de cadenas globales de valor añadido’, ‘Generación de espacios para la creación de marcas de valor añadido’ y ‘Puertos inteligentes mediante la utilización de tecnologías de información y comunicación’.

La Oficina de Puertos realizará un seguimiento de la iniciativa ‘PUERTO 2030’ bajo la premisa de que los puertos se constituyan en elementos de referencia para el desarrollo económico y social de Japón.

by

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Keywords: fishing port, fishing ground, long-term plan, fisheries industry, fishing community

1 INTRODUCTION

There were many good fishing grounds around Japan, the fisheries industry prospered for a long time, and many fishing communities were formed at the coast around the fishing ports. These fishing communities supplied not only marine products but also contributed to the conservation of the natural environment and ecosystem of the area along the shore.

However, the situation surrounding the fisheries has greatly changed. In Japan, with its low birth rate and aging society, while fewer people are employed by the fisheries industry, the average age of employees continues to rise. In addition, fisheries have become less profitable due to a fall in the domestic consumption of marine products and the availability of cheaper imported products. Furthermore, how to properly maintain fishing port facilities has become an urgent issue.

Against this background, the government established ‘Long-Term Plan for Improvement of Fisheries Infrastructure’ (hereinafter: the Long-Term Plan) based on the ‘Fishing Ports and Grounds Improvement Law’ (hereinafter: the Improvement Law) in order to secure sound development of the fisheries industry and the steady supply of marine products. Under this plan, projects related to the fishing ports, the fishing grounds and the fishing communities are being systematically conducted.
2 THE FISHING PORTS AND GROUNDS IMPROVEMENT LAW, AND THE LONG-TERM PLAN FOR IMPROVEMENT OF FISHERIES INFRASTRUCTURE

The Improvement Law that is the basis for the Long-Term Plan was enforced on 1 April 2002, and the first Long-Term Plan started in the same year. Previously, projects related to fishing ports and grounds were carried out under long-term plans which had been established based on other laws. For example, projects related to fishing ports had been carried out based on the Fishing Port Law which was passed in 1950, and Fishing Port Long-Term Plans were established nine times between 1951 and 2001. In addition, projects related to fishing grounds had been carried out based on Coast Fishing Ground Maintenance Development Law passed in 1974, and Coast Fishing Ground Maintenance Development Plans were prepared four times between 1976 and 2001. The total expenses during each planning period were indicated in these long-term plans unlike the current Long-Term Plan.

In June 2001, the Fishing Port Law was radically revised in order to carry out projects related to fishing ports and grounds in a comprehensive and systematic manner. The name was also changed to the Fishing Ports and Grounds Improvement Law which prescribes the current Long-Term Plan.

The period of a Long-Term Plan is set at five years. The draft of the Long-Term Plan is made in line with Basic Policy for Improvement of Fisheries Infrastructure established by the Minister of Agriculture, Forestry and Fisheries. The Minister holds discussions with the prefectural governor concerned and the fisheries policy council prior to establishing policy. In addition, strict procedures are followed when establishing the Long-Term Plan (i.e. a cabinet decision is required, etc.) since the plan greatly affects the lives of citizens and economic activities. These necessary procedures are prescribed in the Improvement Law.

The fourth current Long-Term Plan was adopted at the Cabinet meeting in March 2017; the plan period runs from 2017 to 2021.

3 RELATIONS WITH THE BASIC FISHERY LAW

In Japan, the Basic Fishery Law which prescribes the basic principles under which fisheries are to be developed was enacted with the Improvement Law in 2001. In the Basic Fishery Law, projects related to fishing ports and grounds were recognized as one of the measures to realise a sound development of the fisheries industry. Specifically, it is prescribed to take the measures that are necessary for the projects of the fishing ports, the projects and development of the fishing grounds and the projects of the other infrastructure of the fisheries industry in order to secure a stable supply of marine products, as well as to contribute to the propagation and aquaculture of aquatic animals and plants. In addition, the Basic Fishery Law prescribes the formulation of the Fishery Master Plan to promote the development of fisheries in a comprehensive and systematic manner.
5 MAIN POINT OF THE LONG-TERM PLAN

5.1 Setting of Important Issues

The important issues are set in the Long-Term Plan based on the situation surrounding the domestic and foreign fisheries industry.

For example, the following four important issues were included in the fourth Long-Term Plan to cope with the current conditions facing the fisheries industry such as the increasing demand for global marine products, climate change (specifically, global warming), the increasing magnitude of natural disaster, Japan’s aging society and the promotion of marine product exports, etc.

1) Competitiveness reinforcement initiative and export promotion of the fisheries industry
2) Creation of rich ecosystems and improvement of the production capacity in the sea area
3) Reinforcement of the capacity to respond to large-scale natural disasters
4) Efficient use of fishing ports and activation of fishing communities

5.2 Setting of an Aim and a Quantity of a Project Implementation

The Long-Term Plan prescribes the aim and the quantity of the project implementation. The aim means the result of the outcome type as 5 years result during the plan period of the fourth Long-Term Plan and the quantity of the project means the numbers of implementation for 5 years.

Incidentally, in the fourth Long-Term Plan, two phases of the outcome-type target and output-type target are set from a point of view that showed the conventional unitary target more clearly. This output-type target means a middle goal of the improvement standard necessary to get result to aim.

6 ISSUES RELATED TO FISHING PORT AND GROUND PROJECTS

Based on the current situation surrounding the fisheries industry, important issues which will be addressed in the fourth Long-Term Plan are outlined as follows.

6.1 Competitiveness Reinforcement Initiative and Export Promotion of the Fisheries Industry

Fisheries nationwide are struggling to remain profitable, but the demand for marine products is increasing worldwide. Thus, there is a big opportunity to sell Japanese marine products on the world market.

Therefore, it is necessary to promote the reinforcement of production and distribution function of the marine products in the production areas, secure a steady supply of domestic marine products, and strengthen export promotion measures.

The fourth Long-Term Plan calls for the reorganisation and the integration of handling yards and freezing facilities, and the expansion of quays to cope with large-size fishing vessels in order to address the above issues. These projects will improve the quality of and add value to Japanese marine products, increase production efficiency, reduce costs and stabilise prices.

In addition, projects related to fishing grounds are promoted to secure a production and distribution system that meets both the needs in the export destination country as well as the need to provide a stable supply of marine products for the domestic market.
6.2 Creation of Rich Ecosystems and Improvement of the Production Capacity in the Sea Area

Fishery production of Japan has decreased to half the level of the peak period. About the resources standard around Japan, half of the system group becoming a target of the resources evaluation is low level. In addition, the rise in seawater temperature due to global warming is having a negative effect on the fishing ground environment along the coast. Therefore, it is necessary to promote fisheries environment projects and to cope with the changes in the fishing ground environment due to rising seawater temperatures.

In the fourth Long-Term Plan, a wide-ranging fisheries environment project that places priority on persevering the life cycle of aquatic creatures is being conducted to increase the production capacity of the whole sea area through the creation of a rich ecosystem. In addition, the fishing ground projects that address the rise in seawater temperature are being promoted.
6.3 Reinforcement of the Capacity to Respond to Large-Scale Natural Disaster

In March 2011, heavy damage was inflicted by the Great East Japan Earthquake and subsequent tsunamis. Fishing port facilities were devastated along the Pacific coast of the Tohoku district. Based on the lessons learnt from the Great East Japan Earthquake Disaster, it will be necessary to carry out measures for the large-scale earthquake and tsunami generated by Nankai Trough Earthquake, etc. in the whole of Japan in future. It is also necessary to fortify facilities against increasingly violent typhoons that are believed to be the result of climate change.

The fourth Long-Term Plan includes the following initiatives to cope with the above issues.

1) Introduction of measures to minimise damage to main facilities in the fishing ports, improve evacuation sites and routes in the fishing community, and formulation of hazard maps
2) Formulation of a business continuity plan (BCP) for the purpose of the early recovery of the local fisheries industry
3) Verification of design conditions such as the wave height, improvement of facilities performance against waves, securing measures to ensure a calm water area, etc. will be carried out to cope with increasingly violent typhoons, etc.

![Figure 4: Image of the fisheries environment projects]

![Figure 5: Reinforcement measures of the disaster prevention function of the fishing communities]
6.4 Efficient Use of Fishing Ports and Activation of Fishing Communities

In fishing communities, aging and declining populations are increasing at a rate above that of the national average. In addition, the deterioration of fishing port facilities which are vital to their livelihoods is becoming a critical problem. In order to revitalise fishing communities, proper maintenance of fishing port facilities, improvement of the living and the working environment and diversification will be necessary.

The fourth Long-Term Plan includes the following initiatives to cope with the above issues.

1) Activation of fishing communities through the increase of fishery incomes, the installation of the direct marketing place or the fishing community experience facilities for the purpose of visits of city inhabitants and the foreign tourists to the fishing communities and the diversification of the fisheries industry that utilises existing facilities
2) Improvement of the sanitation environment by the construction of sewerage systems
3) Improvement of working environment by construction of protective facilities against wind and sun, and the construction of floating-type quays
4) Urgent measures for the maintenance of the fishing ports to combat deterioration

7 CONCLUSION

It is thought that the fisheries industry will continue to face severe challenges such as the declining and aging population of fisherman for the time being. In addition, it is thought that the situation surrounding the fisheries industry, such as efficiency of the distribution, sanitation management, and export promotion is constantly changing.

Based on this situation, it is necessary to prescribe measures related to fishing ports and grounds in the Long-Term Plan which will contribute to the sound development of the fisheries industry and the steady supply of marine products.
SUMMARY

The government established the Long-Term Plan for Improvement of Fisheries Infrastructure based on the Fishing Ports and Grounds Improvement Law, in order to secure sound development of the fisheries industry and the steady supply of marine products, and carry out projects related to fishing ports, fishing grounds and fishing communities in a comprehensive and systematic manner.

The Improvement Law was enforced on 1 April 2002, and the first Long-Term Plan started in the same year.

The term of the Long-Term Plan is set at five years. The draft of this Long-Term Plan is made in line with the Basic Policy for Improvement of Fisheries Infrastructure established by the Minister of Agriculture, Forestry and Fisheries.

The current fourth Long-Term Plan was adopted at the Cabinet meeting in March 2017; the period of the plan runs from 2017 to 2021.

Important issues are set in the Long-Term Plan based on the situation surrounding the domestic and foreign fisheries industry.

For example, the following important four issues were set in the fourth Long-Term Plan:

1) Competitiveness reinforcement initiative and export promotion of the fisheries industry
2) Creation of rich ecosystems and improvement of the production capacity in the sea area
3) Reinforcement of the capacity to respond to large-scale natural disaster
4) Efficient use of fishing ports and activation of the fishing communities

The Long-Term Plan prescribes the aim and the quantity of the project implementation. The aim means the result of the outcome type as 5 years result during the plan period of the fourth Long-Term Plan, and the quantity of the project means the numbers of implementation for 5 years.

Based on the situation surrounding the fisheries industry, it is necessary to prescribe measures related to fishing ports and grounds in the Long-Term Plan which will contribute to the sound development of the fisheries industry and the steady supply of marine products.

RESUME

Le gouvernement japonais a élaboré un plan à long terme pour l'amélioration des infrastructures de pêche, fondé sur la loi relative à l'amélioration des ports de pêche et des zones de pêche, afin de garantir le développement rationnel du secteur de la pêche, l'approvisionnement régulier en produits de la mer, et de mettre en œuvre des projets liés aux ports de pêche, lieux de pêche et communautés de pêcheurs de façon globale et systématique.

La loi relative à l’amélioration a été appliquée le 1er avril 2002 et le premier plan à long terme a été lancé la même année.

La durée du plan à long terme est fixée à cinq ans. L’ébauche de ce plan à long terme est conforme à la politique d’amélioration des infrastructures liées à la pêche établie par le ministre de l’Agriculture, des Forêts et de la Pêche.

Le quatrième plan à long terme a été adopté lors de la réunion du Cabinet en mars 2017; ce plan est défini pour la période 2017-2021.

Des sujets importants sont définis dans le Plan à long terme, liés à la situation du secteur de la pêche au Japon et dans le monde.
Par exemple, les quatre sujets suivants ont été définis dans le quatrième Plan à long terme:

1) Initiative de renforcement de la compétitivité et promotion des exportations du secteur de la pêche
2) Création d’écosystèmes riches et amélioration de la capacité de production dans les zones marines
3) Renforcement de la capacité de réaction aux catastrophes naturelles à grande échelle
4) Optimisation des ports de pêche et animation des communautés de pêcheurs

Le plan à long terme est caractérisé en termes d’objectif et de volume au cours de sa période de planification. L’objectif désigne l’aboutissement des projets concernés, et le volume représente le nombre de projets où le plan a été mis en œuvre.

Compte tenu de la situation du secteur de la pêche, il est nécessaire de prescrire dans ce plan à long terme les mesures liées aux ports et aux zones de pêche, qui contribueront au développement rationnel du secteur de la pêche et à l’approvisionnement régulier en produits de la mer.

ZUSAMMENFASSUNG


Das Verbesserungsgesetz trat am 1. April 2002 in Kraft und der erste Langzeitplan begann im gleichen Jahr.

Der Zeitraum des Langzeitplans beträgt fünf Jahre. Der Entwurf dieses Langzeitplans wurde entsprechend der Basisstrategie zur Verbesserung der Fischerei-Infrastruktur vom Ministerium für Landwirtschaft, Forst und Fischerei aufgestellt.

Der aktuelle vierte Langzeitplan wurde vom Kabinett auf der Sitzung im März 2017 angenommen; sein Zeitraum erstreckt sich von 2017 bis 2021.

Wichtige Punkte wurden in dem Langzeitplan festgehalten, die auf der jeweiligen Situation der heimischen und ausländischen Fischerei-Industrie basieren.

Zum Beispiel wurden die folgenden wichtigen vier Punkte in den vierten Langzeitplan aufgenommen:

1) Initiative zur Stärkung der Wettbewerbsfähigkeit und Exportförderung der Fischerei-Industrie.
2) Schaffung reichhaltiger Ökosysteme und Verbesserung der Produktionskapazität im maritimen Bereich.
3) Stärkung der Kapazität, um weitreichende Naturkatastrophen zu bewältigen.
4) Effiziente Nutzung der Fischereihäfen und Unterstützung der Fischereigemeinden.

RESUMEN

El Gobierno ha puesto en marcha un plan de largo plazo para la mejora de las infraestructuras pesqueras, basado en la Ley de Mejora de las Zonas e Instalaciones Pesqueras, de cara a asegurar el desarrollo de la industria y la cadena de suministro de productos relacionados con el mar, mediante el avance de proyectos completos y sistemáticos relacionados con los puertos, zonas y comunidades pesqueras.

La Ley fue promulgada el 1 de abril de 2002, y el primer plan de desarrollo a largo plazo comenzó ese mismo año.

El horizonte de estos planes es de cinco años. El contenido de cada uno de ellos está alineado con la política general de mejora de las infraestructuras pesqueras, establecida por el Ministerio de Agricultura, Forestal y Pesca.

El plan actual es el cuarto que está en vigor y fue aprobado por el Gobierno en marzo de 2017, con un horizonte 2017-2021.

El plan aborda elementos importantes para el desarrollo pesquero, partiendo de la situación existente de esta industria tanto a nivel nacional como internacional.

A modo de ejemplo, algunos elementos clave que se tratan en este cuarto plan resultan ser:

1) Refuerzo de la competitividad y la promoción de la exportación de las industrias pesqueras.
2) Creación de ecosistemas y mejora de la capacidad de producción en el ámbito marino.
3) Refuerzo de la capacidad de respuesta ante desastres naturales a gran escala.
4) Uso eficiente de los puertos pesqueros y activación de las comunidades pesqueras.

El plan describe objetivos y cantidades asociadas a su desarrollo. Los objetivos representan los resultados buscados en un escenario de cinco años como consecuencia de la ejecución del plan, mientras que las cantidades recogen el número de actuaciones llevadas a cabo en dicho periodo.

A la luz de la situación de partida, es necesario definir medidas dentro del plan relacionadas con los puertos y zonas pesqueras que contribuyan al desarrollo de la industria pesquera y garanticen la estabilidad de suministro en las cadenas relacionadas con los productos del mar.
1 INTRODUCTION

Of the various theories concerning the origins of the Japanese people, one of the more convincing explanations holds that maritime people of southern Polynesian stock and people of northern Altaic ancestry mixed with populations that had been living in what is now Japan since ancient times to create today's Japanese. Of those ancestors, the maritime people moved up from the south from island to island over many years or came to Japan from the south via the Chinese mainland. Having moved northward, they arrived in Kyushu and then naturally migrated to the Seto Inland Sea in search of calm waters. Ultimately, this migration brought them to Osaka Bay (specifically, Chinu-no-Umi [the Sea of Chinu]). Abutting this bay is an area that was central to the development of the Japanese people, and starting during the third century CE, maritime trade began in areas of the Seto Inland Sea centered on Chinu-no-Umi, which became an important artery in the development of the Japanese people’s lifestyle and culture. Since almost no roads had been built at the time, the area's residents were forced to rely on maritime transport for long-distance movement of goods and people. As a result, numerous ports developed naturally along the coast of the Seto Inland Sea.

Conditions that determined whether a given location would become a port included the presence of a calm inlet that was shielded from strong winds, a plain beyond the port where people could live, and, most important, a location that allowed the prospective port to be situated an appropriate distance from neighbouring ports so that it could be reached in about a day's sail, which was as much as the sea voyaging technology of the day could accomplish. The port at Kobe had flourished since ancient times as a point of trade with distant mainland China, and during the Edo period (1603-1868), it developed further as a gateway for goods from Kyoto and Osaka, Kyushu and Edo and prospered as a base for trade with the northern land of Ezo (Hokkaido), the destination of the kitamaebune (北前船, ‘northern-bound ships’). Following the opening of the country to the outside world at the end of the Edo period after a long, self-imposed period of isolation, the Port of Kobe developed in dramatic fashion.

2 UP TO THE OPENING OF JAPAN

The Port of Kobe had already developed into a base for maritime transport by around the third century CE, when it was known as the Harbour of Muko (Muko-minato).

During the Nara period (710-794), the port appeared as the Harbor of Owada (Owada-no-Tomari) in a list of ‘5 ports and harbours (Gohaku)’ compiled by the monk Gyoki.
In 812 during the Heian period (794-1185), the government undertook the first port construction work in Japan's history. Furthermore, a number of factors including Taira no Kiyomori’s use of the Harbour of Owada as a base for trade with Song China and the relocation of the capital to Fukuurara drove the growth of the harbour and its surrounding town, which became a bustling community. Around 1173, Kiyomori undertook a series of projects including the construction of Kyogashima, a reclaimed area fronting the Harbour of Owada that would fuel the development of what would later become the Harbour of Hyogo (Hyogo-no-Tsu) and the present-day Port of Kobe.

Figure 1: Kiyomori commanded the construction of the Harbour of Owada (imaginary model)
Source: Kobe Maritime Museum

With the coming of the Kamakura period (1185-1333), the Harbour of Owada came to be known as the Harbour of Hyogo. Trade with mainland China was interrupted following the Mongol invasions that began in 1274, leading to a temporary decline in the harbour’s fortunes.

During the Muromachi period (1336-1573), Ashikaga Yoshimitsu dispatched the first ship on a series of diplomatic missions to Ming China from the Harbour of Hyogo in 1401, and the port once again began to prosper with the opening of trade with China.

Figure 2: Restoration model of a sailing ship used for Japan-China trade
Source: Kobe Maritime Museum

Looking at coastal shipping in the Seto Inland Sea at the time, “the record of the Hyogo North Port Checking Station for Tolls (兵庫北関入船納帳)”, about which Crown Prince Naruhito (the current Emperor of Japan) wrote a pair of academic papers, records a total of 1,960 ships entering the harbour as part of the Seto Inland Sea shipping network, at the heart of which lay the Hyogo North Port Checking Station for Tolls, which is part of the present-day Port of Kobe. Trade flowed through 107 ports along the waterway.
This document provides detailed records of all ships that completed customs procedures in the year 1445 at the Hyogo North Port Checking Station for Tolls (part of the present-day Port of Kobe), where Nara’s Todai-ji Temple, which is famous for its enormous statue of the Buddha, held customs collection rights. Historians worldwide regard it as a valuable record on par with records of export and import customs for the Port of Lubeck in northern Germany dating to the mid 14th century. Crown Prince Naruhito has exhibited an interest in this record since his days as a student, and he has presented two academic papers about the Seto Inland Sea shipping network that was centered on the medieval Port of Kobe.

However, this prosperity proved to be short-lived as the town and harbour of Hyogo suffered devastating damage during the Onin War (1467) and then again during a powerful earthquake that struck the area in 1596. However, Toyotomi Hideyoshi recognised the importance of the Harbour of Hyogo and ordered its reconstruction following the earthquake, allowing a quick recovery.

Even as foreign trade stopped with the closure of the country during the Edo period, the internal situation stabilised. At the time, the country's political heart lay in Edo (Tokyo), while its economic center was Osaka, allowing the Harbour of Hyogo to prosper as the hub of the maritime link between locations nationwide with Osaka and Edo. With the introduction of higaikikaisen (large Japanese junks) in 1619, the opening of a navigation route to Hokkaido through the Sea of Japan by the kitamaebune in 1639, and the introduction of cargo ships known as tarukaisen in 1661, a variety of ships came to visit the Harbor of Hyogo. Despite the closure of the country to outside contacts, the harbor enjoyed frequent use by ships on their way to Edo from the Netherlands and Korea, with which the country enjoyed trade relations.

Figure 3: The folding screens of the late Edo period. The ports and routes of the Seto Inland Sea are shown. Source: Mitsui Bunko Bekkan, Kobe Maritime Museum

Figure 4: Sailing ship models used for domestic trade in the Edo period. Source: Kobe Maritime Museum
3 OPENING OF THE PORT

Commodore Matthew Perry arrived at Uraga with four American warships in 1853 to press for the opening of Japan. Perry signed the Convention of Kanagawa with Japan the following year, prompting other countries to seek diplomatic relations with Japan. The Treaty of Amity and Commerce between the U.S. and Japan in 1858 led to the opening of Japan through a series of similar agreements with other countries, including England and France.

The shogunate had not approved the opening of the Harbour of Hyogo with the opening of the country due to its proximity to Kyoto, but it was with the opening of the Harbour of Hyogo as the Port of Hyogo on 1 January 1868, that the seaport took the first step on its journey to becoming a modern port. Once overseas trade began, a series of construction projects followed to put in place facilities at the port, including a delivery office (to handle customs), repairs to the wharves and warehouses.

4 FROM THE OPENING OF THE PORT TO THE OUTBREAK OF WORLD WAR II

With the opening of the port, the area lying to the west of the Minato River (the old Minato River) was known as the Port of Hyogo, while the area lying to the east of the river was known as the Port of Kobe. Foreign ships tended to anchor in the Port of Kobe. However, an imperial edict issued in 1892 signaled the end of this era of dual ports by designating them both the Port of Kobe, which name remains in use today.

The facility continued to make steady progress toward becoming a modern port with the start of a first phase of construction in 1906 and then a second phase in 1919. Additional construction followed until it was interrupted by World War II. As a result of the construction work, the Port of Kobe gained Pier No. 1 to Pier No. 6 along with Hyogo Pier No. 1 and No. 2 as well as about 6,000 meters of breakwater extensions and about 6,000 meters of shallow-draft wharf extensions. The completion of about 9,000 metres of mooring quays, 36 sheds, wood stock places, and other port facilities established the port’s status as one of Japan’s leading trade ports.

5 AFTER WORLD WAR II

World War II saw the city of Kobe burn to the ground, and the port ceased to function as a result. In addition, the seizure of port facilities by the Allied Forces led to a prolonged period of concern about the restoration of port functions and cargo processing. A plan to widen and dredge Hyogo Canal was finalised in 1946 in order to lay the foundation for the restoration of port functions, and the site became progressively busier following the return of the Hyogo Pier to Japanese administration the next year.
Along with the resumption of private trade on 1 January 1950, special procurement connected with the Korean War led to a boom that revitalised the Japanese economy along with economic conditions at the Port of Kobe. In addition, the enactment of the Port and Harbour Act in May led to the designation of the City of Kobe as the port administrator, a role in which it replaced the national government, in April 1951, and today's port administration system was put in place.

The city worked as port administrator to secure the return of port facilities, leading the U.S. military to progressively relinquish them starting in 1952. By February 1959, all facilities had been returned, and the City of Kobe became the administrator of the Port of Kobe in both theory and practice.

With that development, the harbor's transformation into a modern port resumed along with the area's economic recovery. Construction of Pier No. 7 began in 1952 to deal with growing cargo volume. Work also began on a series of plans, including for the construction of Eastern Port Construction Area No. 1.

6 UP TO THE GREAT HANSHIN-AWAJI EARTHQUAKE OF 1995

The Japanese economy grew dramatically during the mid-1950s. At the same time, ships grew increasingly larger, requiring ports to build even more modern facilities. To deal with this trend, the City of Kobe began construction of Hyogo Pier No. 3 in 1958 and of the Maya Piers in 1959.

Container shipping began during the mid-1960s, marking the start of a trend that would lead to today's wholesale containerisation. The City of Kobe foresaw the coming of the future container era early on and planned container berths for the Maya Wharf, then under construction. The wharf was completed in 1967.

A trend toward motorisation was also underway at the time, and car ferries, which began service in and around the Seto Inland Sea, were growing larger in size and transporting vehicles over increasingly long distances. Recognizing an urgent need for a ferry pier to accommodate those ships, the city began construction of the East Kobe Ferry Pier in 1969 and completed the facility in 1971.

Reclamation of Rokko Island to house modern piers that could accommodate the future quantitative expansion and qualitative transformation of maritime shipping began in 1972 and was completed in 1992.

The second phase of reclamation work for Port Island to accommodate growth in overseas trade, increasingly large ships, and the need to streamline port freight operations began in 1987. The same year, the city also began reclamation work between Pier No. 3 and Pier No. 4 at the Maya Wharf as a redevelopment project to accommodate rapid growth in container freight, and a large public container terminal was completed in 1991. Reclamation work between Hyogo Pier No. 2 and No. 3 as part of a planned improvement of the facilities' ability to function as piers especially handling fruits and vegetables was also completed the same year. Work in the area of the middle pier began in 1992 as part of a redevelopment project designed to create a port where residents could get close to the ocean and a distinctive waterfront. February 1993 saw the opening of all lines of the Harbour Highway, on which construction work had begun in 1967 in an effort to reduce the impact of automobile trafficoriginating in the port on the surrounding city while improving port functions.

Over this period of time, the Seto Inland Sea became a major artery for the movement of people and goods. With regard to the movement of people, ships played a major role in transporting large numbers
of people in a time when expressways and bullet trains had not yet been built, and the calm waters of
the sea made for an ideal route for passenger ships. Motorisation subsequently drove changes in the
type of ships used, from purely passenger ships to ferry boats, but passenger movements to and from
Kobe via the Seto Inland Sea peaked in 1992 at approx. 6,700,000 people per year.

Subsequently, the inauguration of bullet train service in 1975 and the construction of the triple-span
Honshu-Shikoku Bridge from 1988 to 1999 saw a transition in the flow of people from ships to trains and
automobiles. And now, number of passenger movements to and from Kobe via the Seto Inland Sea is
approx. 900,000 people per year.

In this way, the Port of Kobe worked to enhance its functionality and to put in place infrastructure to
accommodate the ongoing transformation in shipping. However, the Great Hanshin-Awaji Earthquake of
17 January 1995 caused devastating damage, and the resulting cessation in port operations exerted an
enormous impact on the city’s economy and residents’ lives, as well as on the movement of goods and
industrial activity in Japan and overseas.

Figure 5: The Great Hanshin Awaji Earthquake caused serious damage to the city area of Kobe along with the
Kobe Port. Left: Collapsed highway, Right: Damaged port facilities.

7 FROM THE GREAT HANSHIN-AWAJI EARTHQUAKE TO THE PRESENT

Although the Port of Kobe suffered enormous damage in the earthquake, the city worked quickly to
restore port functions and reconstruct facilities. Steps were prioritised by around the end of FY1996
(March 1997), and the effort proceeded smoothly. Instead of simply restoring the port to its condition at
the time of the disaster, the city pursued the recovery project in line with a redevelopment plan for the
Maya Wharf, Hyogo Pier, and existing piers in the eastern part of New Harbor in an effort to redevelop
port facilities.

The port also played a major role in recovery operations in the city as reclaimed land between existing
piers and on the southern part of Rokko Island (the northern green area), where work had begun in May
1995, was used to process disaster debris. In this way, reclamation of the area between Maya Wharf
Pier No. 1 and No. 3 was completed in April 1997; of the area between Hyogo Pier No. 1 and No. 2, in
October 1997; and of the area between New Harbour East Wharf No. 5 and No. 8, in July 1999.

By the end of March 1997, operations at all major port facilities at the Port of Kobe had been restored,
allowing the port to resume its role as a gateway port supporting industry in western Japan and
international distribution of goods.

The city subsequently undertook the second phase of the Port Island project and worked to build a high-
standard container terminal on Rokko Island to accommodate growth in international container freight
and increasing ship size, and the Port of Kobe was designated a super hub port by the Japanese
government in July 2005 in order to increase its international competitiveness.
Based on the government’s policy of selecting Strategic International Container Ports as priority infrastructure during additional selection and consolidation targeting major Japanese ports, the Port of Kobe applied along with the Port of Osaka for that status as Hanshin Port. Following this successful bid, the ports were designated as a Strategic International Container Port in August 2010. Today, the public and private sectors together are pursuing a series of comprehensive initiatives with both organisational and infrastructure elements to return to the Port of Kobe supplies that were moved in the aftermath of the Great Hanshin-Awaji Earthquake to nearby ports in Asia in order to maintain and expand the Port of Kobe’s ability to function as a trunk line.

The port has been working since 2011 to strengthen domestic feeder service, in which container freight shipped from the Seto Inland Sea and Kyushu to nearby overseas ports moves through the Port of Kobe in order to boost its role as a freight hub. As a result, the frequency of ships operating as part of the coastal shipping service network linking Kobe with the Seto Inland Sea and Kyushu increased from 68 ships per week in April 2014 to 102 ships per week in June 2018.

8 CONCLUSION

As the easternmost port in a series of ports lying along the Seto Inland Sea, the Port of Kobe has served as a base for exchanges of people and goods since ancient times. With the opening of the port in the 19th century, it developed into a base for multinational flows of people and goods as an international port even as its role as a base for coastal shipping centered on the Seto Inland Sea grew. Although movements of people are shifting from coastal shipping to automobiles and trains with the construction of the three bridges across the Seto Inland Sea waterway, the port’s role as a water transportation hub on the Seto Inland Sea has only grown more unshakable and will continue to do so going forward.

Figure 6: Port of Kobe Future Plan, Port and Urban Projects Bureau, City of Kobe
SUMMARY

Starting during the third century CE, maritime trade began across the Seto Inland Sea, which became an important artery in the development of the Japanese people's lifestyle and culture. Since almost no roads had been built at the time, the area's residents were forced to rely on maritime transport for long-distance movement of goods and people. As a result, numerous ports developed naturally along the coast of the Seto Inland Sea.

Conditions that determined whether a given location would become a port included the presence of a calm inlet that was shielded from strong winds, a plain beyond the port where people could live, and, most important, a location that allowed the prospective port to be situated an appropriate distance from neighbouring ports so that it could be reached in about a day's sail, which was as much as the sea voyaging technology of the day could accomplish. The harbour at Kobe fulfilled these conditions, allowing the area to flourish since ancient times as a point of trade with distant mainland China, as a gateway for goods from Kyoto and Osaka, Kyushu, and Edo while Japan was closed to the outside world, and as a base for trade with the northern land of Ezo (Hokkaido). After being opened to the outside world on 1 January 1868, at the end of the Edo period, the Port of Kobe developed in dramatic fashion.

As they came under bomber attacks during World War II, Kobe's city and harbour lost their ability to function due to heavy damage. After the conflict, port facilities were seized by the Allied Forces, but private trade resumed on 1 January 1950 as special procurement connected with the Korean War led to a boom that revitalised the Port of Kobe.

The City of Kobe foresaw the coming of the future container era early on and planned container berths for the Maya Wharf, then under construction. The wharf was completed in 1967.

Over this period of time, the Seto Inland Sea became a major artery for the movement of people and goods. In particular, ships played a major role in transporting large numbers of people in a time when expressways and bullet trains had not yet been built, and the calm waters of the sea made for an ideal route for passenger ships.

The Port of Kobe suffered enormous damage in the Great Hanshin-Awaji Earthquake on 17 January 1995, and freight volume fell to about half the previous levels after the disaster. Nevertheless, the port was designated as a Strategic International Port by the Japanese government in 2011. It continues to strengthen its ability to serve domestic feeder service, in which container freight shipped from the Seto Inland Sea and Kyushu to nearby overseas ports moves through the Port of Kobe.

In this way, the Port of Kobe has served as a base for exchanges of people and goods since ancient times as the gateway port to the eastern Seto Inland Sea. With the opening of the port 150 years ago, it developed into a base for multinational flows of people and goods as an international port even as its role as a base for coastal shipping centred on the Seto Inland Sea grew. Although movements of people are shifting from coastal shipping to automobiles and trains, the port is poised to continue to play a key role in maritime transport on the Seto Inland Sea.

RESUME

Depuis le troisième siècle de notre ère, le commerce maritime a emprunté la mer intérieure de Seto, qui est devenue une artère importante du développement du mode de vie et de la culture du peuple japonais.

Comme à cette époque il n’existait quasiment aucune route terrestre, les habitants de la région comprenaient sur le transport maritime pour l’acheminement à longue distance de marchandises et de passagers. De ce fait, de nombreux ports se sont développés naturellement le long de la côte de la mer intérieure de Seto.

Un emplacement propice à l’implantation d’un port nécessitait la présence d’une crique protégée des
vents violents, d'une plaine en arrière du port où les gens pouvaient vivre et, le plus important, le futur port devait se situer à une distance appropriée par rapport aux ports voisins correspondant à environ une journée de navigation avec les navires de l'époque. Le port de Kobé remplissait ces conditions, ce qui avait permis à la région de s'affirmer depuis l'antiquité en tant que point de commerce avec la lointaine Chine continentale, et en tant que passerelle pour les marchandises en provenance de Kyoto et d'Osaka, de Kyushu et d'Edo alors qu'à l'époque le Japon était fermé au monde extérieur, et comme base pour le commerce avec l'île d'Ezo au nord (Hokkaido). Après s'être ouvert au monde extérieur le 1er janvier 1868, à la fin de la période Edo, le port de Kobé se développa de façon spectaculaire.

Après les attaques de bombardiers pendant la Seconde Guerre mondiale, la ville et le port de Kobe avaient subi de lourds dégâts et devenus inutilisables. Après le conflit, les forces alliées prirent possession des installations portuaires, mais le commerce reprit le 1er janvier 1950, quand la passation de marchés publics liés à la guerre de Corée entraîna un boom qui dynamisa le port de Kobé.

Très tôt, ville de Kobe a pressenti l'importance de l'arrivée de la future ère des conteneurs et a prévu des postes à conteneurs pour le quai Maya, alors en construction. Le quai Maya a été achevé en 1967.

Duran cette période, la mer intérieure de Seto est devenue une artère majeure pour la circulation des personnes et des biens. Les navires ont notamment joué un rôle majeur dans le transport d'un grand nombre de passagers, à une époque où les autoroutes et les trains à grande vitesse n'existaient pas encore, alors que les eaux calmes de la mer constituaient un itinéraire idéal pour les navires à passagers.

Le 17 janvier 1995, le tremblement de terre de Hanshin-Awaji a fait subir d'énormes dégâts au port de Kobé. Après la catastrophe, le volume de fret a été diminué environ de moitié. Néanmoins, en 2011 le gouvernement japonais a désigné le port de Kobé comme port international stratégique. Il continue de renforcer sa capacité à opérer des services intérieurs, en particulier en expédiant des conteneurs via la mer intérieure de Seto et de Kyushu vers des ports étrangers voisins.

Ainsi, depuis l'Antiquité, le port de Kobé a servi de socle au transport de personnes et de marchandises, étant la porte d'entrée de la partie Est de la mer intérieure de Seto. Depuis sa création il y a 150 ans, Le port de Kobé a suivi l'accroissement du cabotage sur la mer intérieure de Seto, et est devenu un port international accueillant les flux multinationaux de passagers et de marchandises. Bien que la circulation des personnes délaisse la navigation côtière au profit de l'automobile et du train, le port devrait continuer à jouer un rôle clé dans le transport maritime sur la mer intérieure de Seto.

**ZUSAMMENFASSUNG**

Im dritten Jahrhundert n. Chr. begann der Handel auf der Seto-Inlandsee und wurde zu einer bedeutenden Ader in der Entwicklung des japanischen Lebensstils und der japanischen Kultur. Da es zu dieser Zeit fast noch keine Straßen gab, waren die Bewohner dieses Gebiets dazu gezwungen, sich auf den Seetransport für Langstreckentransporte von Waren und Personen zu verlassen. Als Folge davon entwickelten sich zahlreiche Häfen entlang der Küste der Seto-Inlandsee.

Die Voraussetzungen zur Festlegung, ob ein bestimmter Standort zu einem Hafen wurde, beinhalteten das Vorhandensein einer ruhigen Zufahrt, die vor starken Winden geschützt war, und flaches Land außerhalb des Hafens, auf dem Menschen wohnen konnten. Besonders wichtig war, dass der Standort des zukünftigen Hafens in einem angemessenen Abstand zum Nachbarhafen lag, sodass dieser innerhalb eines Tages per Schiff erreicht werden konnte, was der Seereisen-Technologie der damaligen Zeit entsprach. Der Hafen von Kobe erfüllte diese Bedingungen, was dazu führte, dass dieses Gebiet seit frühen Zeiten florierte, als Handelspunkt mit dem entferntesten Festland von China, als Tor für Waren von Kyoto und Osaka, Kyushu und Edo, in einer Zeit als Japan von der Außenwelt abgeschlossen war, und als Basis für den Handel mit dem nördlichen Gebiet von Ezo (Hokkaido). Nach der Öffnung zur übrigen Welt am 1. Januar 1868, am Ende der Edo-Periode, entwickelte sich der Hafen von Kobe auf dramatische Weise.

Sonderbeschaffungen im Zusammenhang mit dem Korea Krieg zu einem Boom führte, durch den der Hafen von Kobe neu belebt wurde.

Die Stadt Kobe sah früh voraus, dass es in der Zukunft eine Container-Ära geben würde, und plante Anleger für Containerschiffe für die sich damals im Bau befindende Maya-Werft. Die Werft wurde 1967 fertiggestellt.

In diesem Zeitraum war die Seto-Inlandsee die Hauptader für den Personenverkehr und den Umschlag von Waren. Insbesondere spielten Schiffe eine große Rolle beim Transport großer Menschenmengen zu einer Zeit, in der Autobahnen und Hochgeschwindigkeitszüge noch nicht gebaut wurden und das ruhige Binnenmeer ideal für die Route von Passagierschiffen war.


Als das Tor zur östlichen Seto-Inlandsee diente der Hafen von Kobe so seit der Antike als Basis für den Austausch von Menschen und Waren. Mit der Eröffnung vor 150 Jahren entwickelte sich der Hafen als Basis für multinationale Ströme von Menschen und Waren zu einem internationalen Hafen, aber auch die Rolle als Basis für die Küstenschifffahrt im Zentrum der Seto-Inlandsee wuchs. Obwohl der Personenverkehr sich von der Küstenschifffahrt zum Auto und zum Zug verlagert, ist der Hafen bereit, eine Schlüsselrolle beim Seetransport auf der Seto-Inlandsee zu spielen.

RESUMEN

Durante el siglo III de nuestra era, el comercio marítimo comenzó a despuntar a lo largo del mar interior de Seto, configurándose como una arteria principal de desarrollo de la cultura y el modo de vida de Japón. Dado que en aquel momento las carreteras eran prácticamente inexistentes, los residentes de la zona debían utilizar el modo marítimo para garantizar el transporte de mercancías y personas, sobre todo si se trataba de largas distancias. Como consecuencia de todo ello, numerosos puertos se fueron estableciendo en la zona costera a lo largo del mar interior de Seto.

Las condiciones naturales que determinaban la ubicación de dichos puertos se basaban en la localización de zonas con cierto abrigo, resguardadas también de los fuertes vientos, así como la existencia de zonas planas adyacentes en tierra sobre las que se pudieran establecer asentamientos humanos, y, lo que era muy importante, que se encontrasen a distancias limitadas de los puertos vecinos de tal forma que se pudiese acceder a ellos en una navegación de alrededor de un día de duración, que era el límite que permitía la tecnología de la época. El puerto de Kobe cumplía todos estos requisitos, lo que permitió que alrededor del mismo floreciese desde un primer momento un área de comercio con la vecina China, actuando como puerta de entrada de las mercancías que se dirigían a Kyoto, Osaka, Kyushu y Edo, en un momento en el que Japón se encontraba cerrado al mundo exterior, configurándose como una plataforma para el comercio con la zona norte de Ezo (Hokkaido). Tras su apertura exterior el 1 de enero de 1868, al finalizar el periodo Edo, el puerto de Kobe se desarrolló de manera espectacular.

Con motivo de los bombardeos acaecidos durante la Segunda Guerra Mundial, la ciudad y el puerto de Kobe perdieron su capacidad operativa debido a los grandes daños sufridos. Tras el conflicto, las instalaciones portuarias fueron incautadas por las fuerzas aliadas, reanudándose de nuevo el comercio internacional a través de las mismas a partir del 1 de enero de 1950, tras la obtención de un permiso especial relacionado con la guerra de Corea que provocó la revitalización del puerto de Kobe.

La ciudad de Kobe intuyó pronto la llegada de la era del contenedor, planificando y desarrollando el muelle Maya, que fue terminado en 1967.
Durante este periodo de tiempo, el mar interior de Seto se transformó en una arteria principal en cuanto al movimiento de personas y mercancías. Particularmente, los buques jugaron un papel muy importante en el tráfico de pasajeros en un momento en el que aún se carecía de autopistas y trenes de alta velocidad, escenario en el cual las calmadas aguas de este mar interior lo hicieron un escenario ideal para el establecimiento de rutas de pasaje.

El puerto de Kobe sufrió daños muy importantes como consecuencia del gran terremoto Hanshin-Awaji que tuvo lugar el 17 de enero de 1995, cayendo los volúmenes de tráfico a aproximadamente la mitad de los existentes antes del seísmo. No obstante, el puerto fue declarado estratégico y de importancia internacional por el Gobierno de Japón en 2011. Continúa mejorando la prestación de servicios asociados a los tráficos de buques feeder locales, de tal manera que los tráficos de contenedores que operan desde el mar de Seto y Kyushu con puertos exteriores se mueven a través de Kobe.

De este modo, el puerto de Kobe se ha configurado como un elemento clave en el intercambio de personas y mercancías desde la antigüedad, actuando como puerta de entrada Este al mar interior de Seto. Con la apertura del puerto hace 150 años, se permitió la aparición de una actividad internacional complementada con su tradicional papel de base de crecimiento asociado al comercio regional alrededor del mar de Seto. Aunque el movimiento de pasajeros se está trasladando a modos tales como el tren o el automóvil, el puerto continúa preparado para jugar un papel fundamental en lo que se refiere al servicio al transporte marítimo en el entorno del mar interior de Seto.
‘CALCIA IMPROVED SOIL’ FOR UTILISING DREDGED SOIL AND STEELMAKING SLAG

by

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Mots-clés : sol amélioré calcia, matériau amélioré calcia, sédiments de dragages, polders, recifs artificiels

1 INTRODUCTION

Dredged soil generated from the dredging works for maintaining shipping lane and ship basins generally contains a lot of fine grains (silt and clay) and has a high water content ratio. Therefore, it is difficult to use it directly as a good geo-material, and thus most of the dredged soil has been disposed at a sediment disposal site.

In recent years, however, as it was difficult to construct new sediment disposal sites due to limited available space in coastal areas and the need to protect the environment, technology for effectively using soft dredged soil has been demanded.

On the other hand, because a large amount of high-quality geo-materials is necessary in order to make artificial shallows or tidelands for restoration of marine environments and reclamation lands for new ports or offshore airports, it is expected that a part of such high-quality geo-materials are to be made of the recycling materials such as steelmaking slag.

Based on this background, by means of mixing the converter-type steelmaking slag generated in the steel manufacturing process to the soft dredged soil, ‘Calcia improved soil’ which is a way of utilisation for improving the physical and chemical properties of dredged soil was developed. Calcia improved soil has the ability of improving the shear strength of the dredged soil, the ability of suppressing turbidity, and the ability of purifying seabed sediment by absorbing phosphorous and sulfide. Therefore, it can be used for landfill construction materials, and also applied to the filling materials for shallows or tidelands and the dredging depression in order to regenerate the good marine environment (refer to Figure 1-1).

This paper describes the raw materials and characteristics of calcia improved soil at first, then introduces two examples of applying calcia improved soil to a large-scale land reclamation work and a construction work of artificial shallows for regenerating fishery.
2 RAW MATERIALS OF CALCIA IMPROVED SOIL

Calcia improved soil is manufactured by clayey dredged soil and ‘calcia improving material’, which is the product made of converter type steelmaking slag.

2.1 Dredged Soil

Dredged soil to be used for calcia improved soil is soft clay which contains more than 20 % of fine fraction content. It is difficult to use it as it is for port construction. Examples of properties of dredged soil used for calcia improved soil are shown in Table 2-1.

<table>
<thead>
<tr>
<th>Dredged area</th>
<th>arent</th>
<th>Organic matter</th>
<th>Gravel</th>
<th>Sand</th>
<th>Clay</th>
<th>Silt and Clay</th>
<th>Liquid limit</th>
<th>Plastic limit</th>
<th>Plasticity index</th>
<th>Dissolution of Si</th>
<th>Calc</th>
<th>Insolubles</th>
<th>Ignition loss</th>
<th>TOC</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tokyo bay 1</td>
<td>140</td>
<td>1.29</td>
<td>0.7</td>
<td>5.6</td>
<td>53.7</td>
<td>93.7</td>
<td>138.0</td>
<td>56.4</td>
<td>81.6</td>
<td>5.0</td>
<td>0.02</td>
<td>13.5</td>
<td>2.4</td>
<td>8.4</td>
<td></td>
</tr>
<tr>
<td>200</td>
<td></td>
<td>1.24</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tokyo bay 2</td>
<td>70</td>
<td>1.60</td>
<td>0.4</td>
<td>53.6</td>
<td>45.8</td>
<td>58.0</td>
<td>138.0</td>
<td>30.2</td>
<td>27.8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>140</td>
<td></td>
<td>1.30</td>
<td>0.0</td>
<td>4.2</td>
<td>95.8</td>
<td>124.0</td>
<td>42.2</td>
<td>81.8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mikawa bay</td>
<td>140</td>
<td>1.45</td>
<td>6.3</td>
<td>39.3</td>
<td>54.4</td>
<td>113.0</td>
<td>39.1</td>
<td>73.9</td>
<td>1.3</td>
<td>0.05</td>
<td>19.1</td>
<td>1.7</td>
<td>8.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>200</td>
<td></td>
<td>1.48</td>
<td>0.2</td>
<td>21.7</td>
<td>78.1</td>
<td>66.0</td>
<td>24.7</td>
<td>41.3</td>
<td>2.2</td>
<td>0.01</td>
<td>9.4</td>
<td>1.2</td>
<td>7.8</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Table 2-1: Properties of dredged soil*

2.2 Calcia Improving Material

Converter type steelmaking slag, which is raw material of ‘Calcia improving material’, is a by-product generated in the refining process which manufactures steel in converter from pig iron produced in a blast furnace. Calcia improving material is like a crushed stone obtained by cooling and pulverising the steelmaking slag for controlling component management and particle size distribution. The steelmaking slag after steam aging treatment has been commonly used to roadbed materials. Recently, the authors have developed a new technology to be used for improving the property of dredged soil containing high fine fraction content, because it contains free lime (f - CaO). Tables 2-2 and 2-3 show examples of physical properties and chemical composition of calcia improving material.
Table 2-2: Physical characteristics of calcia improving material

<table>
<thead>
<tr>
<th></th>
<th>Surface dry density (g/cm³)</th>
<th>Dry density (g/cm³)</th>
<th>Water absorption content (g/cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steelmaking slag</td>
<td>3.00</td>
<td>2.90</td>
<td>2.35</td>
</tr>
</tbody>
</table>

Table 2-3: Chemical component of calcia improving material: unit %

<table>
<thead>
<tr>
<th>Component</th>
<th>CaO</th>
<th>f-CaO</th>
<th>SiO₂</th>
<th>Al₂O₃</th>
<th>MgO</th>
<th>MnO</th>
<th>FeO</th>
<th>Fe₂O₃</th>
<th>P₂O₅</th>
<th>T-S</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steelmaking slag</td>
<td>40.0</td>
<td>3.98</td>
<td>10.7</td>
<td>2.77</td>
<td>6.28</td>
<td>5.43</td>
<td>8.17</td>
<td>13.40</td>
<td>1.50</td>
<td>0.08</td>
</tr>
</tbody>
</table>

3 CHARACTERISTICS OF CALCIA IMPROVED SOIL

3.1 Shear Strength Improvement Effect

3.1.1 Improvement of Immediate Shear Strength Due to Water Absorption

During mixing, the calcia improving material absorbs the water of the dredged soil, so that the shear strength of the mixture of dredged soil and the calcia improving material is higher than dredged soil. Photo 3-1 shows the difference of the cylinder flow test between the dredged soil and the calcia improved soil immediately after mixing. In this case the calcia improved soil was made of mixing 70 vol% of dredged soil with water and 30 vol% of calcia improving material.

![Photo 3-1: Cylinder flow test results of dredged soil and calcia improved soil](image)

3.1.2 Improvement of Shear Strength Due to Hydration Reaction Over Time

Ca contained in the calcia improving material reacts with Si and Al contained in the dredged soil to form CSH hydrate or Afm hydrate in the same manner as the cement reaction, thereby the shear strength of calcia improved soil is considered to be improved.

Figure 3-1 shows the relationship between time and unconfined compression strength of the calcia improved soil which was mixed with 70 vol% of dredged soil and mixed and 30 vol% of calcia improving material. From Figure 3-1, it was found that the shear strength gradually increased until 90 days.

Figure 3-2 shows the effect of the volume mixing ratio of calcia improving material to the unconfined compression strength of calcia improved soil. When calcia improving material was less than 40 vol%, the shear strength of calcia improved soil increased as more calcia improving material was mixed.
Actually, the shear strength of the calcia improved soil was determined not only due to the properties of dredged soil used, that is, water content, fine particle content, ignition loss and mineral composition, but also due to the properties of calcia improving material used, that is, calcium content (f-CaO), particle size composition, etc. Therefore, it is necessary to confirm the strength of calcia improved soil by pre-mixing test with the dredged soil and the calcia improving material to be actually used.

### 3.2 Effect of Turbidity Suppression

Photo 3-2 shows the state of turbidity generation when (a) only dredged soil and (b) calcia improved soil immediately after mixing were put into water respectively. Turbidity when calcia improved soil was poured into water was suppressed to about 1/3 to 1/4 of turbidity when only dredged soil was poured. It is because calcia improving material absorbs water in dredged soil, therefore the viscosity of the calcia improved soil improves and it became difficult to separate. This makes it possible to reduce countermeasures against turbidity such as pollution prevention films, etc. when placing calcia improved soil into seawater. In addition, when calcia improved soil is placed onto the seabed, there is also an effect of suppressing the rolling up of the mud deposited on seabed because of covering the mud with calcia improved soil.

### 3.3 Effect of Suppressing Elution of Phosphoric Acid and Sulfide

Converter type steelmaking slag contains much calcium and iron. These Ca, Fe and alkali has the effect of immobilising phosphoric acid and sulfide which are rich in the dredged soil and making it difficult to elute in water.

In the experiment, 100 g of calcia improved soil mixed with 30 vol% of calcia improving material was placed in a glass bottle, and then 900 ml of artificial sea water aerated with nitrogen was injected. To investigate the influence of sulfide, 50 mg of glucose was incorporated into the dredged soil for
promoting the generation of sulfide. The specimens were cured for 60 days under sealed, light blocking, and room temperature curing condition. Figures 3-3 and 3-4 show the concentrations of dissolved sulfide and $PO_4^- - P$ in artificial seawater, respectively. Comparing the results of the case of dredged soil alone and that of calcia improved soil, the concentration of dissolved sulfide and $PO_4^- - P$ were much reduced under calcia improved soil. These results show that elution of sulfide and phosphoric acid can be suppressed when calcia improved soil is used in seawater.

3.4 Environmental Safety

3.4.1 Safety Against Hazardous Substance Elution

‘Technical Utilisation Manual of Calcia Improved Soil for Construction of Port, Airport and Coast’ specifies the environmental safety quality (criteria for elution amount and content of harmful substances) to be satisfied by dredged soil and calcia improving material applied to calcia improved soil. According to the manual, the dredged soil should meet the Standard of Bottom Sediment in Marine Pollution Prevention Law, and the calcia improving material should satisfy the environmental safety quality prescribed in JIS K 0058. From numerous test results, it was confirmed that the calcia improved soil does not amplify elution of hazardous substances and it satisfies predetermined environmental standards. Table 3-1 shows an example of elution test results according to Standard of Bottom Sediment in Marine Pollution Prevention Law when calcia improved soil was used in the sea.

<table>
<thead>
<tr>
<th>Substance</th>
<th>Result</th>
<th>Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>As</td>
<td>mg/L</td>
<td>$&lt;0.005$</td>
</tr>
<tr>
<td>Cd</td>
<td>mg/L</td>
<td>$&lt;0.002$</td>
</tr>
<tr>
<td>Cu</td>
<td>mg/L</td>
<td>$&lt;0.005$</td>
</tr>
<tr>
<td>Hg</td>
<td>mg/L</td>
<td>$&lt;0.005$</td>
</tr>
<tr>
<td>Pb</td>
<td>mg/L</td>
<td>$&lt;0.1$</td>
</tr>
<tr>
<td>Arsenic compounds</td>
<td>mg/L</td>
<td>$&lt;0.01$</td>
</tr>
<tr>
<td>Antimony compounds</td>
<td>mg/L</td>
<td>$&lt;0.01$</td>
</tr>
<tr>
<td>As</td>
<td>mg/L</td>
<td>$&lt;0.003$</td>
</tr>
<tr>
<td>Cr</td>
<td>mg/L</td>
<td>$&lt;0.5$</td>
</tr>
<tr>
<td>Cu</td>
<td>mg/L</td>
<td>$&lt;0.05$</td>
</tr>
<tr>
<td>Fe</td>
<td>mg/L</td>
<td>$&lt;0.1$</td>
</tr>
<tr>
<td>Nickel</td>
<td>mg/L</td>
<td>$&lt;0.001$</td>
</tr>
<tr>
<td>Manganese</td>
<td>mg/L</td>
<td>$&lt;0.01$</td>
</tr>
<tr>
<td>Ni</td>
<td>mg/L</td>
<td>$&lt;0.01$</td>
</tr>
<tr>
<td>Zn</td>
<td>mg/L</td>
<td>$&lt;0.05$</td>
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<tr>
<td>Cd</td>
<td>mg/L</td>
<td>$&lt;0.5$</td>
</tr>
<tr>
<td>Hg</td>
<td>mg/L</td>
<td>$&lt;0.005$</td>
</tr>
<tr>
<td>Pb</td>
<td>mg/L</td>
<td>$&lt;0.1$</td>
</tr>
<tr>
<td>As</td>
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<td>$&lt;0.003$</td>
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<tr>
<td>Cr</td>
<td>mg/L</td>
<td>$&lt;0.5$</td>
</tr>
<tr>
<td>Cu</td>
<td>mg/L</td>
<td>$&lt;0.05$</td>
</tr>
<tr>
<td>Fe</td>
<td>mg/L</td>
<td>$&lt;0.1$</td>
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<tr>
<td>Ni</td>
<td>mg/L</td>
<td>$&lt;0.01$</td>
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<td>Zn</td>
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<tr>
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<td>Ni</td>
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<td>Zn</td>
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<tr>
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</tr>
<tr>
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<tr>
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<td>As</td>
<td>mg/L</td>
<td>$&lt;0.003$</td>
</tr>
<tr>
<td>Cr</td>
<td>mg/L</td>
<td>$&lt;0.5$</td>
</tr>
<tr>
<td>Cu</td>
<td>mg/L</td>
<td>$&lt;0.05$</td>
</tr>
<tr>
<td>Fe</td>
<td>mg/L</td>
<td>$&lt;0.1$</td>
</tr>
<tr>
<td>Ni</td>
<td>mg/L</td>
<td>$&lt;0.01$</td>
</tr>
<tr>
<td>Zn</td>
<td>mg/L</td>
<td>$&lt;0.05$</td>
</tr>
<tr>
<td>Cd</td>
<td>mg/L</td>
<td>$&lt;0.5$</td>
</tr>
<tr>
<td>Hg</td>
<td>mg/L</td>
<td>$&lt;0.005$</td>
</tr>
<tr>
<td>Pb</td>
<td>mg/L</td>
<td>$&lt;0.1$</td>
</tr>
<tr>
<td>As</td>
<td>mg/L</td>
<td>$&lt;0.003$</td>
</tr>
<tr>
<td>Cr</td>
<td>mg/L</td>
<td>$&lt;0.5$</td>
</tr>
<tr>
<td>Cu</td>
<td>mg/L</td>
<td>$&lt;0.05$</td>
</tr>
<tr>
<td>Fe</td>
<td>mg/L</td>
<td>$&lt;0.1$</td>
</tr>
<tr>
<td>Ni</td>
<td>mg/L</td>
<td>$&lt;0.01$</td>
</tr>
<tr>
<td>Zn</td>
<td>mg/L</td>
<td>$&lt;0.05$</td>
</tr>
<tr>
<td>Cd</td>
<td>mg/L</td>
<td>$&lt;0.5$</td>
</tr>
<tr>
<td>Hg</td>
<td>mg/L</td>
<td>$&lt;0.005$</td>
</tr>
<tr>
<td>Pb</td>
<td>mg/L</td>
<td>$&lt;0.1$</td>
</tr>
<tr>
<td>As</td>
<td>mg/L</td>
<td>$&lt;0.003$</td>
</tr>
</tbody>
</table>

Table 3-1: Elution test result
3.4.2 Safety Against High pH Water Elution

Several attempts had been made to apply the steelmaking slag in seawater, but there was concern as to whether high pH water eluted from slag would affect the surrounding environment.

Figure 3-5 shows the results of comparative tests on the pH elevation when steel slag was immersed singly or when it was immersed as calcia improved soil in a beaker containing artificial seawater. In the case of calcia improved soil, it was found that very small rise of pH was observed. The mechanism to be hard to elute high pH in calcia improved soil is shown as an image in Figure 3-6. It is because the slag particles are wrapped in impermeable dredged soil immediately after mixing, and it is because calcium in slag and silica in soil react to be solidified over time.

<table>
<thead>
<tr>
<th>Only Steel Slag</th>
<th>Calcia Soil</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Out-looking of materials" /></td>
<td><img src="image2" alt="Out-looking of materials" /></td>
</tr>
<tr>
<td><img src="image3" alt="Immersion into seawater" /></td>
<td><img src="image4" alt="Immersion into seawater" /></td>
</tr>
</tbody>
</table>

Figure 3-5: Comparison of pH

Figure 3-6: Mechanism to decrease pH in calcia improved soil

3.4.3 Safety to Aquatic Living Things

In order to confirm whether calcia improved soil does not adversely affect aquatic living things when used in seawater, acute toxicity test using supernatant liquid after stirring and leaving with calcia improved soil was carried out.

In this test, at first, a test stock solution was prepared by the method shown in Figure 3-7. Then, the test solutions of five concentrations, 0 %, 7.7 %, 14.6 %, 27.7 %, 52.6 %, 100 %, were prepared by diluting the stock solution with sea water. And red sea breams, black abalones and shrimps in each ten individuals were bred, and mortality rates of them were observed for 96 hours.

Figure 3-7: Procedure of acute toxicity test for living things
Table 3-2 shows the test results for black abalones. As shown in Table 3-2, the mortality rate was 0 %, even with the highest concentration condition, and it was confirmed that calcia improved soil does not affect the growth of aquatic living things.

### 4 EXAMPLE OF APPLICATION TO LARGE-SCALE RECLAMATION WORK – NAGOYA MOTOHAMA PIER

#### 4.1 Outline of the Project

The outline of this project is shown in Table 4-1, the position of sites, the plan view and the cross-sectional view are shown in from Figure 4-1 to Figure 4-3, and the photographs taken before and after construction are shown in Photo 4-1.
This reclamation work was carried out using calcia improved soil made of mixing dredged soil in Nagoya port and calcia improving material generated from Nagoya Steel Works of Nippon Steel Corporation. As shown in Table 4-1, the landfill constructions were executed dividing into East Area and West Area. The properties of the dredged soil and the calcia improving material used in this work are shown in Table 4-2. The fine fraction contents of dredged soils were between 30 and 90 %, the water content ratios were above the liquid limit.

Here, the construction method and quality control method in the West Area were described.

### Table 4-2: Properties of dredged soil and calcia improving material

<table>
<thead>
<tr>
<th>Consistency</th>
<th>Unit</th>
<th>Dredged soil</th>
<th>Calcia improving material</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Area A</td>
<td>Area B</td>
</tr>
<tr>
<td>Soil density</td>
<td>p( g/cm³)</td>
<td>2.64</td>
<td>2.65</td>
</tr>
<tr>
<td>Liquid limit</td>
<td>w_L( %)</td>
<td>110</td>
<td>58.5</td>
</tr>
<tr>
<td>Plastic limit</td>
<td>w_p( %)</td>
<td>38.5</td>
<td>31.9</td>
</tr>
<tr>
<td>Plasticity index</td>
<td>IP</td>
<td>71.3</td>
<td>26.6</td>
</tr>
<tr>
<td>Grain size distribution (% Area)</td>
<td>25</td>
<td>15.9</td>
<td>14.0</td>
</tr>
<tr>
<td>Wet density</td>
<td>g/cm³</td>
<td>1.303</td>
<td>1.636</td>
</tr>
<tr>
<td>Ignition loss</td>
<td>IL( %)</td>
<td>11.6</td>
<td>8.5</td>
</tr>
<tr>
<td>Initial water content</td>
<td>w_0( %)</td>
<td>171</td>
<td>73.3</td>
</tr>
<tr>
<td>Initial water content/liquid limit</td>
<td>w_0/w_c</td>
<td>1.56</td>
<td>1.25</td>
</tr>
</tbody>
</table>

### 4.2 Construction Method Applied

In West Area, construction was conducted at the rate of from 3,000 to 4,000 m³/day of reclamation during the construction period. Two construction methods, ‘Pneumatic flow mixing method’ and ‘Drop mixing method by reclaimer barge’ were developed and applied as a method suitable for a large-scale and a rapid construction.

‘Method 1: Pneumatic flow mixing method’ mixes dredged soil and calcia improving material by turbulent effect in the transporting pipe from the pneumatic conveyer (see Figure 4-4). These kinds of methods
have been popularly achieved in Japan for the case of cement improved soil. But since there was no experience in this method with calcia improved soil, the facility was modified for using crushed slag and was applied to this project. Although there was an advantage in this method that calcia improved soil can be transported at high speed even to about 500 m away by prolonging the pressure feed pipe, there was a disadvantage that the cost was high because of using expensive facilities, and that abrasion tended to occur in the pressure feed pipe.

**Method 1: Pneumatic Flow Mixing Method**

![Pneumatic Flow Mixing Method Diagram](image)

Figure 4-4: Pneumatic flow mixing method (Method 1)

‘Method 2: Drop mixing method by reclaimer barge’ is a method of continuously supplying dredged soil and calcia improving material on a belt conveyor of reclaimer barge, providing collision boards at connecting portions of belt conveyors and at falling portion from a spreader conveyor. Mixing two types of materials homogenously by collision energy as seen in Figure 4-5. This method was newly developed in this project by performing many preliminary tests such as checking the falling height to ensure the quality of mixing.

**Method 2: Drop Mixing Method by Reclaimer Barge**

![Drop Mixing Method by Reclaimer Barge Diagram](image)

Figure 4-5: Drop mixing method by reclaimer barge (Method 2)

In Method 1, for the purpose of protecting the equipment, it is necessary to set the water content ratio to a certain level or higher for the pneumatic feeding. On the other hand, in Method 2, dredged soil with a lower water content than Method 1 can be used, so the amount of substantial part of the dredged soil can be increased. As a result, there is an advantage that the construction cost per unit volume of dredged soil can be reduced. In consideration of the advantages and disadvantages of both methods in the construction work, the pneumatic flow mixing method was applied to a place distant from the quay wall, and the drop mixing method was applied to the place near the quay wall (see Photo 4-1).
4.3 Mix Design Method of Calcia Improved Soil and Quality Control

4.3.1 Mix Design Method of Calcia Improved Soil and the Target Indoor Mixing Strength

The undrained shear strength of the saturated clay is 1/2 of the unconfined compression strength $q_u$ measured in the confined compression test. Thus, the shear strength of calcia improved soil can also be evaluated by unconfined compression strength.

The mix design method of calcia improved soil conforms to ‘Technical Manual on Pneumatic Flow Mixing Method’, published by Coastal Development Institute of Technology. Thus, the ratio at which the unconfined compression strength falls below the design standard strength, which is defined as the defect rate, should be managed so as not to exceed the allowable value.

Defining the design standard strength of the landfill site as $q_{uck}$, the in-situ average strength as $q_{uf}$ and the target indoor mixing strength as $q_{ul}$, these have the following relationships (shown in Figure 4-6).

$$q_{uck} = (1-\alpha \nu) q_{uf}$$

$$q_{ul} = q_{uf} / \beta$$

$\alpha$ : coefficient obtained from the defect rate

$\nu$ : coefficient of variation

$\beta$ : ratio of the unconfined compression strength between in-situ and indoor

The design standard strength of this landfill site was $q_{uck} = 30 \text{ kN/m}^2$. Here, when the defect rate was set to 25 %, $\alpha = 0.67$. And the ratio $\beta$ was obtained as 0.6 from the preliminary field test results on the calcia improved soil. By substituting $\beta = 0.6$, $\nu = 0.23$ into the above equation, the target indoor mixing strength is calculated as $q_{ul} = 60 \text{ kN/m}^2$, $q_{uf} = 36 \text{ kN/m}^2$.

![Figure 4-6: Mix design method of calcia improved soil](image)

4.3.2 Results of Pre-Mixing Test

The water content of the dredged soil sampled at the site was 1.56 w/L, but the moisture content would fluctuate at the time of actual construction. The pre-mixing tests were carried out with the water content ratio varied in the range of 1.4 to 1.8 w/L.

Here, the mixing ratio of calcia improving material is changed to at 30 % ± 5 %. After undergoing curing in the thermostatic chamber, unconfined compression strength tests were conducted. Here, the target indoor strength of calcia soil $q_{ul}$ was decided as to satisfy more than 60 kN/m² within 90 days after construction. Figure 4-7 shows the results of the unconfined compression strength in the preliminary mixing test. It shows that the mixing ratio of calcia improving material was 25 % to achieve the target strength even with water content ratio of 1.8 w/L within 90 days after curing. The volume ratio of the calcia improving material was determined to 25 %, based on the above results.

![Figure 4-7: Results of pre-mixing tests](image)
As a quality control of in-situ shear strength, unconfined compression tests were conducted on samples taken from each hopper barge throughout the entire construction period. Figure 4-8 shows the measurement results of the unconfined compression strength of calcia improved soil. In the pneumatic flow mixing method, the average strength was 100 kN/m², the coefficient of variation was 0.44, and in the drop mixing method, the average strength was 115 kN/m² and the coefficient of variation was 0.51. In both methods, it was confirmed that in both mixing methods, the unconfined compression strength of the sample collected at the site almost satisfied the design standard strength, and the defect rate was less than 2 % and that it was sufficiently smaller than 25 %.

![Figure 4-8: Strength distribution of calcia soil throughout construction period](image)

At six months after the completion of the landfill construction, Automatic Ram Sounding and Surface Wave Survey were carried out to confirm whether the strength of the entire landfill ground was secured and uniform. These results proved that landfill ground almost satisfied the design strength throughout the landfill site.

5 EXAMPLE OF APPLICATION TO ARTIFICIAL SHALLOWS – AIMING FOR COASTAL FISHERY REGENERATION

5.1 Outline of the Project

In the sea area of Aboshi at Himeji City, the catch of coastal fishery has been decreasing due to flood mud sediment from the Ibo-River. Therefore, an experimental project aimed at regenerating the fishing field by means of constructing artificial shallows with calcia improved soil on the seabed was conducted. This is because the seabed was raised by the embankment made of calcia improved soil, so that it was expected that the bottom mud would be covered, and light could easily reach the seabed, and that the seaweed bed would grow.

<table>
<thead>
<tr>
<th>Project</th>
<th>1st stage</th>
<th>2nd stage</th>
<th>3rd stage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project</td>
<td>Experimental Shallows Construction Project for Restoring fishery off shore Aboshi in Himeji City</td>
<td>Fisheries Cooperative Association of Himeji City</td>
<td>Nippon Steel &amp; Sumitomo Metal Corporation</td>
</tr>
<tr>
<td>Owner (Project entity)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Orderer</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Contractor</td>
<td>Penta – Ocean Construction Co., Ltd</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Construction Period</td>
<td>from July to Sep. in 2015</td>
<td>from May to Sep in 2017</td>
<td>from May to Sep in 2018</td>
</tr>
<tr>
<td>Area of Shoal (surface)</td>
<td>2,450 m²</td>
<td>14,700 m²</td>
<td>5,200 m²</td>
</tr>
<tr>
<td>Amount of Calcia Soil</td>
<td>10,100 m³</td>
<td>55,000 m³</td>
<td>36,000 m³</td>
</tr>
<tr>
<td>Amount of Covering Stone</td>
<td>Natural stone 2,110 m³, Artificial Slag Stone 1,920 m³</td>
<td>Artificial Slag Stone 15,000 m³</td>
<td>Artificial Slag Stone 17,200 m³</td>
</tr>
</tbody>
</table>

Table 5-1: Outline of the Himeji project
As shown in Table 5-1, the experimental work from 2015 was divided into three stages and a total area of 2 hectares of the shallows was constructed. After construction, the monitoring surveys on sediment quality, water quality and living things were conducted every year, and the effect of shallows to the surrounding environment and the effect on fishing ground regeneration were evaluated. Figure 5-1 shows a schematic diagram of the construction stage of shallows, a plan view, and a cross-sectional view. The artificial shallows were constructed with calcia improved soil in filling part and with natural stone or slag artificial stone in cover part.

![Schematic diagram](image1)

**Figure 5-1: Schematic diagram, plan and section of the artificial shallows**

### 5.2 Construction Method of Shallows

<table>
<thead>
<tr>
<th>Table 5-2 Work flow</th>
<th>Figure 5-2: Position of constructing shallows by calcia improved soil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dredging work at Hirohata sea route</td>
<td></td>
</tr>
<tr>
<td>Transportation of the dredged soil</td>
<td></td>
</tr>
<tr>
<td>Calcia improving work: mixing by backhoe</td>
<td></td>
</tr>
<tr>
<td>Transportation of the calcia soil</td>
<td></td>
</tr>
<tr>
<td>Constructing mound by placing calcia soil</td>
<td></td>
</tr>
<tr>
<td>Completing shallows by covering with stone</td>
<td></td>
</tr>
</tbody>
</table>

Table 5-2 shows the work flow of constructing the shallows where calcia improved soil was applied, and Figure 5-2 shows the site of the dredging work, the making calcia improved soil work, and the creating shallows work respectively. Photo 5-1 shows the state of construction for each work flow. The dredging work was carried out by a 7-m³ grab dredger on the shipping lane of the Hirohata Works and the dredged soil was transported to Yumesaki quay in Hirohata Works by hopper barge with a 650-m³ capacity. At Yumesaki quay the hopper barge with dredged soil was loaded with calcia improving material with a
3.5-m³ backhoe and then the dredged soil and the calcia improving material were mixed for 90 minutes on the same backhoe to produce calcia improved soil. Calcia improved soil in the barge was transported to the shallow construction site in Aboshi and was loaded with a crane-equipped barge with 5 m³ grab and was placed on the seabed as filling materials of the shallows. After that, the surface was covered with natural stone or slag artificial stone.

![Photo 5-1: Status of each construction work](image)

**Table 5.3: Properties of dredged soil and calcia improving material**

<table>
<thead>
<tr>
<th>Item</th>
<th>Measurement method</th>
<th>Mean value Measured</th>
<th>Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dredged Soil</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wet density</td>
<td>JIS A 1225</td>
<td>1.26</td>
<td>N.A.</td>
</tr>
<tr>
<td>Water content</td>
<td>JIS A 1203</td>
<td>2.0%</td>
<td>N.A.</td>
</tr>
<tr>
<td>Liquid limit</td>
<td>JIS A 1205</td>
<td>14.0%</td>
<td>N.A.</td>
</tr>
<tr>
<td>Fine fraction content</td>
<td>JIS A 1204</td>
<td>98.8%</td>
<td>≥ 20%</td>
</tr>
<tr>
<td>Table flow</td>
<td>JIS A 313</td>
<td>12.7 cm</td>
<td>N.A.</td>
</tr>
<tr>
<td>Elution of toxic substances (34 items)</td>
<td>MOE Notice No.14</td>
<td>Below criteria</td>
<td>Criteria for sediment of seabed in Marine Pollution Control Law</td>
</tr>
<tr>
<td>Calcia Material</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Density in saturated surface-dry condition</td>
<td>JIS A 1109</td>
<td>2.77</td>
<td>N.A.</td>
</tr>
<tr>
<td>Unit weight</td>
<td>JIS A 1104</td>
<td>1.50</td>
<td>N.A.</td>
</tr>
<tr>
<td>F CaO</td>
<td>JIS* standard</td>
<td>3.15%</td>
<td>≥ 1.0% *Iron &amp; Steel Inst. of Japan</td>
</tr>
<tr>
<td>Elution of toxic substances (9 items)</td>
<td>JIS K 0058-1</td>
<td>Below criteria</td>
<td>Standard applied to marine construction work in JIS K 0058-1</td>
</tr>
</tbody>
</table>

**Figure 5-3: Distribution of unconfined compression strength of calcia improved soil**

**Table 5.4: Quality control items of calcia improved soil**

<table>
<thead>
<tr>
<th>Items</th>
<th>Measurement method</th>
<th>Mean value Measured</th>
<th>Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wet density</td>
<td>JIS A 1225</td>
<td>1.56 kN/m²</td>
<td>N.A.</td>
</tr>
<tr>
<td>Table flow</td>
<td>JIS A 313</td>
<td>89.4 mm</td>
<td>80mm ≤ Table flow ≤ 230mm</td>
</tr>
<tr>
<td>Unconfined compression strength</td>
<td>JIS &amp; JIS 1236</td>
<td>133 kN/m²</td>
<td>q₁₀ ≤ 28 kN/m² Design standard strength</td>
</tr>
<tr>
<td>Vane shear strength at 5-day curing</td>
<td>JIS 1411</td>
<td>2.29 kN/m²</td>
<td>≥ 5.0 kN/m²</td>
</tr>
</tbody>
</table>

**Figure 5-4: Location of survey points**
Properties of the dredged soil and the calcia improving material applied to the construction are shown in Table 5-3 and quality control items of calcia improved soil are shown in Table 5-4, respectively.

For the quality control of the calcia improved soil, unconfined compression tests were conducted at the age of 28 days. The tests were carried out using samples taken from the hopper barge once a day. The distribution of the unconfined compression strength of the calcia improved soil is shown in Figure 5-3. All calcia improved soils exceeded the design standard strength in situ \( q_{uc}=28 \text{kN/m}^2 \) and the defect rate was 0 %.

5.3 Results of Monitoring Survey

5.3.1 Survey Procedure

The monitoring surveys were regularly implemented every year after shallows construction. In this paper, the results of the survey carried out at the first stage site were described in detail. Figure 5-4 shows the location of the survey points and measurement lines. Here, following survey items were carried out in prescribed timing.

- Mound shape survey: immediately after construction, 14 months after construction
- Sediment quality, water quality survey: before construction, 2 months, 5 months, 8 months, 14 months after construction
- However, elution test of toxic substances and water quality test are not carried out after 5 months
- Biological survey: before construction, 2 months, 5 months, 8 months, 14 months, 20 months after construction

5.3.2 Stability of Mound Shape

The shape of the mounds was investigated by narrow multi beams. Figure 5-5 shows the survey results. Although the settlement of about 20 cm due to consolidation of bottom mud was observed, the mound was stable and was not affected by two typhoons which attacked this area during 14 months from the construction.

5.3.3 Survey of Seabed Sediment and Water Quality

Elution tests of 34 items of hazardous substances specified in Standard of Bottom Sediment in Marine Pollution Control Law were conducted. From this survey, it was confirmed that in all tested items the detected values were below the criterion values as shown in Table 5-5.

Figures 5-6 and 5-7 show the values of COD and sulfide (T-S) intensity of the soil sampled at TP-1 in Figure 5-4 above the exposed part of calcia improved soil and the surrounding mud. It was found that above the calcia improved soil area significantly lower COD and the sulfide intensity were observed.
compared with above the surrounding mud area. These results showed that there was an effect of purifying bottom sediment by replacing calcia improved soil from original mud.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1 alkylmercuric compound</td>
<td>mg/L</td>
<td>0.0005</td>
<td>None</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
</tr>
<tr>
<td>2 mercury compound</td>
<td>mg/L</td>
<td>0.0005 ≤ 0.005</td>
<td>≤ 0.1</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
</tr>
<tr>
<td>3 cadmium compound</td>
<td>mg/L</td>
<td>0.003 ≤ 0.1</td>
<td>≤ 0.1</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
</tr>
<tr>
<td>4 lead compound</td>
<td>mg/L</td>
<td>0.005 ≤ 0.1</td>
<td>≤ 0.1</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
</tr>
<tr>
<td>5 organic phosphorous compound</td>
<td>mg/L</td>
<td>0.1 ≤ 1</td>
<td>≤ 0.1</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
</tr>
<tr>
<td>6 chromate compounds</td>
<td>mg/L</td>
<td>0.02 ≤ 0.5</td>
<td>≤ 0.1</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
</tr>
<tr>
<td>7 arsenic compound</td>
<td>mg/L</td>
<td>0.005 ≤ 0.1</td>
<td>≤ 0.1</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
</tr>
<tr>
<td>8 cyanide; cyanogen compound</td>
<td>mg/L</td>
<td>0.1 ≤ 1</td>
<td>≤ 0.1</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
</tr>
<tr>
<td>9 polychlorinated biphenyl</td>
<td>mg/L</td>
<td>0.0005 ≤ 0.003</td>
<td>≤ 0.3</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
</tr>
<tr>
<td>10 copper compound</td>
<td>mg/L</td>
<td>0.01 ≤ 3</td>
<td>≤ 0.3</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
</tr>
<tr>
<td>11 zinc compound</td>
<td>mg/L</td>
<td>0.01 ≤ 2</td>
<td>≤ 0.3</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
</tr>
<tr>
<td>12 fluorine compound</td>
<td>mg/L</td>
<td>0.1 ≤ 15</td>
<td>≤ 0.3</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
</tr>
<tr>
<td>13 trichloroethylene</td>
<td>mg/L</td>
<td>0.002 ≤ 0.3</td>
<td>≤ 0.3</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
</tr>
<tr>
<td>14 tetrachloroethylene</td>
<td>mg/L</td>
<td>0.0005 ≤ 0.1</td>
<td>≤ 0.3</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
</tr>
<tr>
<td>15 beryllium compound</td>
<td>mg/L</td>
<td>0.01 ≤ 2.5</td>
<td>≤ 0.3</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
</tr>
<tr>
<td>16 chromium compound</td>
<td>mg/L</td>
<td>0.01 ≤ 2</td>
<td>≤ 0.3</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
</tr>
<tr>
<td>17 nickel compound</td>
<td>mg/L</td>
<td>0.01 ≤ 1.2</td>
<td>≤ 0.3</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
</tr>
<tr>
<td>18 vanadium compound</td>
<td>mg/L</td>
<td>0.01 ≤ 1.5</td>
<td>≤ 0.3</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
</tr>
<tr>
<td>19 dichloromethane</td>
<td>mg/L</td>
<td>0.002 ≤ 0.2</td>
<td>≤ 0.3</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
</tr>
<tr>
<td>20 tetrachloroethane</td>
<td>mg/L</td>
<td>0.0005 ≤ 0.002</td>
<td>≤ 0.3</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
</tr>
<tr>
<td>21 1,2-dichloroethane</td>
<td>mg/L</td>
<td>0.0004 ≤ 0.04</td>
<td>≤ 0.3</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
</tr>
<tr>
<td>22 1,1-dichloroethylen</td>
<td>mg/L</td>
<td>0.002 ≤ 0.4</td>
<td>≤ 0.3</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
</tr>
<tr>
<td>23 Cs-1, 2-dichloroethylen</td>
<td>mg/L</td>
<td>0.004 ≤ 0.4</td>
<td>≤ 0.3</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
</tr>
<tr>
<td>24 1, 1,1-trichloroethane</td>
<td>mg/L</td>
<td>0.003 ≤ 0.3</td>
<td>≤ 0.3</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
</tr>
<tr>
<td>25 1, 1,2-trichloroethane</td>
<td>mg/L</td>
<td>0.006 ≤ 0.3</td>
<td>≤ 0.3</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
</tr>
<tr>
<td>26 1, 3-dichloropropene</td>
<td>mg/L</td>
<td>0.0002 ≤ 0.002</td>
<td>≤ 0.3</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
</tr>
<tr>
<td>27 thiourea</td>
<td>mg/L</td>
<td>0.0006 ≤ 0.06</td>
<td>≤ 0.3</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
</tr>
<tr>
<td>28 sultaine</td>
<td>mg/L</td>
<td>0.0003 ≤ 0.03</td>
<td>≤ 0.3</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
</tr>
<tr>
<td>29 thiocarbonate</td>
<td>mg/L</td>
<td>0.002 ≤ 0.3</td>
<td>≤ 0.3</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
</tr>
<tr>
<td>30 benzene</td>
<td>mg/L</td>
<td>0.001 ≤ 0.1</td>
<td>≤ 0.3</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
</tr>
<tr>
<td>31 selenium compound</td>
<td>mg/L</td>
<td>0.001 ≤ 0.1</td>
<td>≤ 0.3</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
</tr>
<tr>
<td>32 1, 4-Dioxane</td>
<td>mg/L</td>
<td>0.005 ≤ 0.1</td>
<td>≤ 0.3</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
</tr>
<tr>
<td>33 organochlorine compound</td>
<td>mg/kg</td>
<td>2 ≤ 40</td>
<td>≤ 10</td>
<td>0.0040</td>
<td>0.00014</td>
<td>0.00071</td>
<td>0.00084</td>
</tr>
<tr>
<td>34 dioxins</td>
<td>pg·TCEq/L</td>
<td>≤ 10</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 5-5: Results of elution tests for calcia soil according to Marine Pollution Control Law

![Figure 5-6: COD of seabed sediment](image)

![Figure 5-7: Total sulfide of seabed sediment](image)
Regarding the water quality survey, the tests of 27 items prescribed in Environmental Standard of Water Quality for Human Health Protection were conducted as shown in Table 5-6. It was confirmed that in all items the detected values of water quality tests were below the criterion values.

Figures 5-8 and 5-9 show DO of sea water and pH measurement results immediately above the calcia improved soil exposed part (TP-1 in Figure 5-4) respectively. Detected values of DO were more than 6 mg/l. It means level of DO satisfied the fishery water standard. In Figure 5-9, the detected values of pH immediately above the calcia improved soil exposed part and the control point in the mouth of Ibo River are shown. The arrows in the figure indicate the distribution range of the measured values in the vertical.
direction at each measuring points. Because both the calcia exposure point and the control point are
influenced by Ibo River, the pH value fluctuates greatly. But the maximum value of the pH of the water
immediately above the calcia exposed part is almost equal to the maximum value of the control point
and it is within the range of the standard of fishery water. Two red horizontal lines in the figure show its
range regulated by this standard. Therefore, the influence of pH on the surrounding seawater due to
casting calcia improved soil is considered to be small.

5.3.4 Living Things

An underwater video survey was carried out and investigation of alterations in a number of species,
degree of coverage and population of algae and animals were carried out in order to confirm whether
the growth of seaweed and animals would change before and after constructing the artificial shallows.

Photo 5-4 shows the habitat status of living things in the experimental site at 8 months after the
construction. The appearance of sea cucumber and asciadiaea, and fishes such as scorpion fish was
observed. Photo 5-5 shows the growth of algae in the experimental site at 20 months after construction
(May 2017). It was observed that some algae like Desmarestia viridis and Undaria pinnatifida were
growing at the top of the natural stone and artificial stone in the experimental site.

Figures 5-10 and 5-11 show the alteration of the coverage degree of algae and the number of individuals
of animals with time respectively, up to 20 months after constructing the shallows. At both the natural
stone part and artificial stones part in the experimental site, the coverage degree of algae increased
over time, and it was approaching to the habitat status of living things in the existing revetment. From
these facts, it was confirmed that the habitat status of living things was improved by constructing the
artificial shallows due to the effect of sealing the seabed mud and the effect of raising up the seabed
level. In addition, it was demonstrated that there is a possibility of regenerating a fishing ground by
constructing an artificial shallow even using calcia improved soil.
CONCLUSION

- Calcia improved soil is made by mixing the clayey dredged soil and the calcia improving material which is the product made of steelmaking slag.
- Calcia improved soil has the following characteristics.
  - Clayey dredged soil is improved by calcia improving material. It is because calcia improving material absorbs the water in dredged soil immediately after mixing, and it is because Si and Al in dredged soil and Ca in calcia improving material cause chemical reaction after time passing.
  - Calcia improved material has the effect of suppressing turbidity and elution of phosphoric acid and sulfide in seawater and/or seabed.
  - Calcia improved soil does not increase pH in the surrounding seawater when used in the sea.
- Calcia improved soil was applied to the large-scale reclamation work in Nagoya Port.
  - Two construction methods were developed for the large-scale landfill work. One was ‘Pneumatic flow mixing method’ and the other was ‘Drop mixing method by reclaimer barge’.
  - Mixing design method of calcia improved soil was established.
  - It was confirmed that the ground having shear strength satisfying the design standard strength was created by means of on-site quality control.
- The shallows for fishery regeneration was created using calcia improved soil in Himeji Port, and the monitoring surveys were regularly implemented every year.
  - The mound made of calcia improved soil was stable against twice typhoons attack.
  - Even when calcia improved soil was placed onto seabed, there was no bad influence on the surrounding water quality.
  - Because the seaweed and marine organisms were grown in the shallows created in this project, it was suggested that shallows constructed from calcia modified soil may contribute to fishery regeneration.

REFERENCES

- Coastal Development Institute of Technology of Japan (2017): “Technical Utilization Manual of Calcia Improved Soil for Construction of Port, Airport, and Coast”.


**SUMMARY**

Large quantity of dredged soil generated due to dredging of routes and berths is difficult to use as it is because it contains a lot of fine grain content, it is soft and it has a high water content ratio. 'Calcia improved soil' was developed which was a utilisation technology for improving physical and chemical properties of dredged soil, by means of mixing the converter-type steelmaking slag generated in the steel manufacturing process to the soft dredged soil. And the technical development has been also implemented to apply calcia improved soil to landfill material and to the material of tidelands and shallows for regenerating fishery.

Calcia improved soil has the property of improving strength over time by cement reaction, the property of suppressing turbidity when used in seawater, and the property of insolubilising phosphorus and sulfide in dredged soil. In addition, when calcia improved soil is used in seawater, it is confirmed that it is also safe material for marine organisms without causing environmental influences such as elution of heavy metals, elution of high pH water.

In this paper, as examples of effective utilisation of calcia improved soil in actual seas, we introduced the case applied to landfill construction at Nagoya Port and the case applied to shallows construction off shore Himeji City.

In landfill at Nagoya Port, 470,000 m³ of calcia improved soil was applied to reclaim the sea area with an average depth of about 5 m to create 85,000 m² of land. The landfill site could be completed by satisfying the target strength throughout the entire area by daily quality control, and a great reduction in construction period could be realised because ground improvement after landfill was unnecessary.

Shallow field construction work at Himeji was aimed at improving the fishing ground which had been decreasing in catch due to the landfill construction etc. Shallow mound was constructed by means of raising calcia improved soil by 3 to 4 m on the coastal seabed. After the shallow mound construction, as the results of monitoring survey over three years, it was proved that durability of shallow mounds, environmental safety, growth of algae and marine organisms was confirmed, and that the artificial shallow construction was effective to regenerate fishery field.

**RESUME**

La réutilisation de grandes quantités de sédiments de dragage de chenaux et des berges est difficile du fait la forte proportion de fines qu’ils contiennent, qu’ils sont meubles et de leur forte teneur en eau.

C’est pour pallier cette situation que la méthode d’amélioration des sols « Calcia » a été mise au point.

Cette technologie consiste à améliorer les propriétés chimiques et physiques des sédiments en les mélangeant à des laitiers sidérurgiques. La méthode permet la réutilisation du sol amélioré comme remblais, pour la construction de polders et de récifs artificiels.

Le sol amélioré Calcia a pour propriétés d’augmenter la résistance à long terme par cimentage, de ne pas créer de turbidité lorsqu’il est utilisé en mer, et de fixer le phosphore et les sulfures, les rendant insolubles dans l’eau. En outre, l’utilisation du sol amélioré Calcia dans l’eau de mer a été confirmé.
comme un matériau qui est compatible avec la vie des organismes marins, qui n’induit pas de problèmes environnementaux tel que le rejet de métaux lourds ou d’eau avec un pH élevé.

Cet article présente des retours d’expériences sur l’utilisation du sol amélioré Calcia en mer; construction d’un polder au port de Nagoya, et construction d’un haut-fond artificiel au large de la ville de Himeji.

Le polder de Nagoya est constitué de 470 000 m$^3$ de remblai en sol amélioré Calcia, appliqué en mer à la profondeur moyenne de 5 m, pour gagner une surface exploitable de 85 000 m$^2$. Les objectifs en termes de résistance ont été atteints grâce à un contrôle qualité quotidien, et comme le traitement des sols n’est pas nécessaire après mise en place, le délai de construction a pu être réduit.

La construction du récif artificiel de Himeji avait pour but de compenser les effets de la construction du polder sur le stock de pêche. Le récif artificiel est constitué d’une couche de sol amélioré calcia d’une épaisseur de 3 à 4 m au-dessus du fond marin. Après sa construction, son suivi sur trois ans a démontré la stabilité du récif, la sécurité environnementale, le développement d’algues et de micro-organismes, et l’efficacité du récif dans la reconstitution du stock de pêche.

**ZUSAMMENFASSUNG**


Als Beispiel für die Anwendung der „Calcia Improved Soil“ Methode in Meeren wird in diesem Artikel die Anwendung in einer Auffüllung im Hafen von Nagoya und bei dem Einbau von Untiefen vor der Küste von Himeji-Stadt dargestellt.

Bei der Auffüllung im Hafen von Nagoya wurden 470 000 m$^3$ „Calcia Improved Soil“ verwendet, um aus dem Meer 85 000 m$^2$ Land mit einer durchschnittlichen Tiefe von ca. 5 m zu gewinnen. Bis zum Abschluss der Auffüllung wurde die zu erreichende Sollstärke durch tägliche Qualitätskontrolle überwacht. Die Bauzeit konnte drastisch reduziert werden, da eine Bodenverbesserung nach der Auffüllung unnötig war.

RESUMEN

Una importante cantidad del material que se genera durante las operaciones de dragado de canales y muelles es de difícil reutilización debido a que poseen gran cantidad de material fino, tienen baja capacidad portante y poseen un alto contenido de agua. La técnica del ‘suelo mejorado Calcia’ se ha desarrollado con el objetivo de mejorar las características físico-químicas de los materiales procedentes de dragado, mezclándolos con escorias procedentes del proceso de fabricación del acero. El desarrollo de esta técnica se ha llevado también a cabo en procesos de relleno con terreno mejorado y en zonas de regeneración pesquera.

El suelo mejorado Calcia tiene como propiedades principales el aumento de las condiciones resistentes a través del proceso de cementación producido, la eliminación de la turbidez cuando se utilice en aguas marinas, así como la insolubilidad de los elementos de fósforo y sulfurosos en el material de dragado. Adicionalmente, cuando el suelo mejorado Calcia se ha utilizado en el entorno marítimo se ha confirmado que resulta seguro para los organismos marinos, sin causar impactos ambientales tales como la elución de metales pesados o la aparición de aguas con elevados niveles de pH.

En este artículo se ponen como ejemplos de utilización del suelo mejorado Calcia el caso de obras de relleno en el puerto de Nagoya y el caso de la construcción en zonas someras de un área exterior en la ciudad de Himeji.

En el caso del puerto de Nagoya, se utilizaron 470.000 m$^3$ de material mejorado como relleno, en una zona con alrededor de 5 m de profundidad, para la generación de una superficie de 85.000 m$^2$. Esta operación se llevó a cabo garantizando unas adecuadas características resistentes del terreno, tras un proceso de control diario del mismo, lo que permitió también una reducción del plazo total de ejecución ya que se hizo innecesario cualquier tratamiento posterior de mejora.

Los trabajos desarrollados en aguas someras en Himeji se dirigían a mejorar la producción pesquera de una zona que había ido perdiendo su capacidad extractiva por elementos tales como obras de relleno en la zona, etc. Las actuaciones llevadas a cabo han consistido en el vertido de una capa de entre 3 y 4 m de suelo mejorado Calcia sobre el lecho marino. Tras esta actuación, y llevado a cabo un seguimiento de la misma durante tres años, se ha puesto de manifiesto la durabilidad de la solución, la mejora medioambiental acaecida, el crecimiento de algas y organismo marinos, así como la regeneración de las condiciones pesqueras de la zona.
INTRODUCTION

The technical standard for port facilities in Japan went through a major revision in 2007 and 2018. A complete version of the technical standard written in Japanese is available from the Ports and Harbours Association in Japan (www.phaj.or.jp). A semi-complete version in English is available from the Overseas Coastal Area Development Institute of Japan (www.ocdi.or.jp/en).

One could point out two remarkable features of the earthquake resistant design of port structures in Japan: one is that it is based on site-specific design ground motions; both L1 and L2 design ground motions are evaluated with considerations of the source, path and site effects. To achieve the quality control of design ground motions, the technical standard encourages temporary in-situ earthquake observation at the site for construction. The other remarkable feature is that it pays close attention to the residual deformation of ground; quantitative evaluation of the deformation of a soil-structure system is included as part of the design procedure. The purpose of this article is to describe these two essential aspects of the earthquake resistant design of port structures in Japan.

SITE-SPECIFIC DESIGN GROUND MOTIONS

2.1 Importance of Site Effects

Generally speaking, strong ground motions are determined by three effects, namely, the source effect, the path effect and the site effect as shown in Figure 1. The source effect is defined as the effect of the rupture process of the earthquake. The path effect is defined as the effect of the materials along the propagation path from the source to the bedrock beneath the site. The site effect is defined as the effect of sediments below the site down to the bedrock. The bedrock here is defined as a layer with a shear wave velocity over 3,000 m/s [OCDI, 2009], which corresponds to fresh granite in Japan.

The existence of sediments below the site has significant effects on the amplitude, frequency content and duration of strong ground motions. It is important to note here that the ‘sediments’ involve not only shallow soil deposit with SPT N values smaller than 50 (shear wave velocities smaller than about 300 m/s) but also deeper firm ground with N values greater than 50 (shear wave velocities ranging from 300-3,000 m/s). Seismic waves are mainly amplified due to the contrast of shear wave velocity. Because the contrast of shear wave velocity between the surface and the bedrock is sometimes as large as 20 (=3,000/150), seismic waves are significantly amplified by the existence of the sediments. At the same
time, the frequency content of strong ground motions is closely related to the thickness of the sediments. If the sediments are thin enough, then only high-frequency component of strong ground motions will be amplified, which is a favorable condition for large-scale structures. But if the sediments are thicker, then frequency components closer to the natural frequency of large-scale structures may be amplified. In this case seismic design should be performed carefully.

![Diagram showing source, path, and site effects](image.png)

*Figure 1: Source, path and site effects*

It is important to recognize here that the characteristics of deeper firm ground, which is usually beyond the reach of ordinary geotechnical investigations including SPT, have significant effects on the amplification of seismic waves, because the contrast of shear wave velocity within deeper firm ground itself is as large as 10 (=3,000/300).

Figure 2 shows an example of the importance of the site effect. The left panel shows the topography around the Port of Sakai, west Japan. Two observation stations, namely, Sakaiminato-G (Strong Motion Earthquake Observation in Japanese Ports) and JMA (the Japan Meteorological Agency) are located in the plains of Yumigahama Peninsula in the left-hand side of the photo. Other two stations, namely, SMN001 of K-NET [Kinoshita, 1998] and SMNH10 of KiK-net [Aoi et al., 2000] are located in mountainous Shimane Peninsula in the right-hand side of the photo. Observed peak ground velocities during the 2000 Tottori-ken Seibu earthquake (Mj7.3) were approximately four times greater for the plains of Yumigahama Peninsula than for mountainous Shimane Peninsula (the right panel of Figure 2). The difference can be attributed to the amplification of seismic waves due to the sediments beneath Yumigahama Peninsula. Thus, evaluation of the site effect is fundamentally important to predict strong ground motions from future large earthquakes and to determine design ground motions. If we neglect the site effect in the evaluation of design ground motions, it may lead to an overestimation or underestimation of seismic load sometimes by a factor of 4 or more.

![Image of topography and velocity waveforms](image.png)

*Figure 2: The topography around the Port of Sakai, west Japan (left) and the velocity waveforms for the fault-normal component recorded around the port during the 2000 Tottori-ken Seibu earthquake (Mj7.3)*
Figure 3: Fourier spectra of past major strong motion records obtained at Hachinohe Port (NS component) and Kansai International Airport (Runway-normal component)

Figure 3 shows an example of the effect of the sediments on the frequency content of strong ground motions. At Hachinohe Port, both of the Fourier spectra from the 1968 Tokachi-oki earthquake ($M_{J}=7.9$) and the 1994 Sanriku Haruka-oki earthquake ($M_{J}=7.5$) are characterised by a peak at the frequency of 0.4 Hz (the period of 2.5 seconds). The former record is famous as ‘Hachinohe wave’ and was widely used for the design of port structures in Japan in the past. On the other hand, at Kansai International Airport, both of the Fourier spectra from the 1995 Hyogo-ken Nanbu earthquake ($M_{J}=7.3$) and the 2000 Tottori-ken Seibu earthquake ($M_{J}=7.3$) are characterised by a peak at the frequency of 0.2 Hz (the period of 5 seconds). The difference of the predominant periods can be attributed to the thickness of sediments down to the bedrock at each observation station. These observations reveal how important it is to consider site-specific design ground motions. If we use, for example, ‘Hachinohe wave’ for the design of structures at Kansai International Airport, then earthquake response analysis of structures will wrongly tell us that the response of structures with a natural period of 5 seconds are small, which is a misleading result because the structure will actually be exposed to a strong ground motion with a predominant period of 5 seconds at Kansai International Airport.

In view of the importance of the site-specific nature of earthquake ground motions, both L1 and L2 design ground motions are evaluated as site-specific ground motions. The L1 ground motion is defined as a ground motion with high probability of occurrence at the site during the design working life. The L2 ground motion is defined as the largest ground motion among ground motions at the site from scenario earthquakes. The L1 ground motions have been evaluated through probabilistic seismic hazard analyses with considerations of the source, path and site effects and have been posted at the website of the National Institute for Land and Infrastructure Management (http://www.ysk.nilim.go.jp/kakubu/kouwan/sisetu/sisetu.htm). The L2 ground motions are evaluated based on scenario-based approaches, with considerations of the source, path and site effects as follows.

2.2 Brief Introduction to Strong Motion Simulation

There are several methods to generate site-specific design ground motions. In this section, the method based on site-specific amplification and phase characteristics [Kowada et al., 1998; Nozu and Sugano, 2008; Nozu et al., 2008] will be described.
First, a small earthquake is hypothesised, whose area is equal to the area of the asperity of the target earthquake divided by $N^2$ and whose final slip is equal to the final slip of the asperity divided by $N$. The ground motion from the small earthquake is called the ‘Green’s function’. The Fourier amplitude of the Green’s function is evaluated as a product of the source spectrum $S(f)$, the path effect $P(f)$ and the site amplification factor $G(f)$.

The source spectrum of the small event is assumed to follow the $\omega^{-2}$ model [Aki, 1967]. Figure 4 shows the displacement, velocity and acceleration source spectra following the $\omega^{-2}$ model. As for the path effect, it is a common practice to take into account both the geometrical spreading and the inelastic damping.

![Source spectra which follow the $\omega^{-2}$ model](image)

As for the site amplification factor, those obtained from in-situ earthquake observation should be used. The site amplification factors at permanent earthquake observation stations in Japan evaluated by Nozu and Nagao (2005) are available at [http://www.pari.go.jp/bsh/jbn-kzo/jbn-bsi/taisin/siteamplification_jpn.html](http://www.pari.go.jp/bsh/jbn-kzo/jbn-bsi/taisin/siteamplification_jpn.html). However, before using the data, it is necessary to make sure (by using, for example, microtremor observations) that the characteristics of ground motions do not differ significantly between the site of construction and the permanent observation station. If the characteristics of ground motions are found to be different between them, it is necessary to conduct a temporary in-situ earthquake observation at the site of construction to evaluate the site amplification factor depending on the importance of the structure (see the next section).

As for the Fourier phase of the Green’s function, the Fourier phase of a record at the earthquake observation station can be used. If several records are available at the site, it is recommended to choose an event which has a similar incident angle and a similar backazimuth with the target asperity. The Green’s function in the frequency domain can be written as follows.

$$S(f)*P(f)*G(f)*\left|O_s(f)\right|_p,$$

where $O_s(f)$ is the Fourier transform of a record at the site and $\left|O_s(f)\right|_p$ is its Parzen-windowed amplitude (band width of 0.05 Hz is used). The time domain Green’s function can be obtained as the inverse Fourier transform of the equation (1). Finally, the time domain Green’s function can be superposed (e.g. Miyake et al., 1997) to obtain the ground motion from the entire asperity (Figure 5). When two or more asperities are considered, contribution from all the asperities should be superposed. A computer program to synthesise strong ground motions based on the method described above is open to public from the Port and Airport Research Institute ([http://www.pari.go.jp/bsh/jbn-kzo/jbn-bsi/taisin/sourcemodel/somodel_program.html](http://www.pari.go.jp/bsh/jbn-kzo/jbn-bsi/taisin/sourcemodel/somodel_program.html)). The source parameters for the simulation can be determined either following the guideline provided by OCDI (2009) or based on detailed investigation on the target earthquake.
The method has been applied to past damaging earthquakes in Japan. Figure 6 shows the simplified source model developed for the 2003 Tokachi-oki, Japan, earthquake (Mj8.0) composed of three asperities or SPGAs. In Figure 7, synthetic velocity waveforms (0.2-1.0 Hz) at three stations are compared with the observed ones. It should be noted that the observed waveforms show significant variability from site to site, from an impulsive waveform at TKCH07 to a long-tailed waveform at TKCH03. These characteristics are accurately reproduced in the simulation, because site-specific amplification and phase characteristics are considered in the simulation.
Figure 7: Observed (gray) and synthetic (red) velocity waveforms (0.2-1.0 Hz) at TKCH07, HKD095 and TKCH03 during the 2003 Tokachi-oki, Japan, earthquake (M8.0).

2.3 Importance of In-Situ Earthquake Observation

In the evaluation of design ground motions using the techniques described above, the reliability of the result is obviously dependent on the quality of the evaluation of the site effects. To achieve the quality control of design ground motions, the technical standard encourages temporary in-situ earthquake observation. Recall that the characteristics of deeper firm ground, which is usually beyond the reach of ordinary geotechnical investigations including SPT, have significant effects on the amplification of seismic waves. In-situ earthquake observation is the most efficient, economical, and reliable tool for the evaluation of the site effects in seismically active countries like Japan.

Because the site for construction of important infrastructures is often fixed years before its design procedure, a well-organised design programme will allow us to conduct temporary observation of earthquake ground motions at the site for construction before the design procedure begins. The term for the temporary observation should be determined taking into account the seismicity of the area. Typically, in Japan’s case, a term of 1-3 years would be required. The seismometers used for the observation should cover all the frequency range for which strong ground motions should be predicted. The location of the observation should also be determined carefully. When it is difficult to install the seismometer just at the construction site, then microtremor observation should be conducted in and around the construction site and the seismometer should be installed within an area in which the characteristics of microtremor can be regarded as uniform.

Once earthquake records are obtained, the site amplification factor at the temporary station can be evaluated based on the known site amplification factors at permanent stations as follows. The first step is to find earthquakes which are recorded both at the temporary station and the surrounding permanent stations. Then, for these earthquakes, the source spectra should be determined so that the synthetic spectra at permanent stations are consistent with the observed ones. It is a common practice to assume that the source spectra follow the \( \omega^{-2} \) model (Figure 4). Finally, using the source spectra thus obtained and the observed spectra at the temporary station, the site amplification factor at the temporary station can be determined.
A simplified version of this analysis can be applied if the temporary station is close enough to a permanent station for which the site amplification factor is known. In this case, these stations share the same source effect and the same path effect. Therefore, the Fourier spectral ratio of the records from the same earthquake at these stations represents the ratio of the site amplification factors. Thus, the site amplification factor for the temporary station can be easily obtained as the spectral ratio multiplied by the site amplification factor at the permanent station.

Figure 8 shows an example of the result of temporary in-situ earthquake observation conducted by the Chugoku Regional Development Bureau, Ministry of Land, Infrastructure, Transport and Tourism, Japan, to reveal the site effects at the Port of Iwakuni. The vertical axis shows the ratio of the observed Fourier amplitude at the temporary station at the Port of Iwakuni with respect to a nearby permanent station (YMG016). The temporary observation was conducted for about six months in 2005. From the result, it can be recognised that the site amplification factor at the temporary station is greater by a factor of 10 around 1 Hz and smaller by a factor of 10 around 2 Hz with respect to YMG016. Such a significant difference in the site amplification factors can be interpreted as a consequence of the effects of sediments including deeper firm ground (with shear wave velocity ranging from 300-3,000 m/s) because the difference of shallow soil layers alone cannot explain such a significant difference. Therefore, this is an example in which the site effects, including the effects of deeper firm ground, which is beyond the reach of ordinary geotechnical investigations, were efficiently revealed by conducting temporary in-situ observation of earthquake ground motions.

Figure 8. An example of the result of temporary in-situ earthquake observation conducted at the port of Iwakuni by the Chugoku Regional Development Bureau, Ministry of Land, Infrastructure, Transport and Tourism, Japan. The vertical axis shows the Fourier spectral ratio of the records at the Port of Iwakuni with respect to YMG016.

3 CLOSE ATTENTION TO THE DEFORMATION OF SOIL-STRUCTURE SYSTEM

3.1 Lessons Learnt From the 2016 Kumamoto Earthquake Sequence

The performance of port structures subject to earthquake ground motions is significantly affected by the residual deformation of ground. Case histories encountered during the reconnaissance activities for the 2016 Kumamoto earthquake sequence recalled this principle.

The 2016 Kumamoto earthquake sequence hit Kumamoto and Oita prefectures, Kyushu, Japan, with the largest event of Mj7.3. In response to the occurrence of the earthquake sequence, the National
Institute for Land and Infrastructure Management and the Port and Airport Research Institute dispatched reconnaissance teams to the affected area. In contrast to serious damage to some infrastructures, the damage to port facilities was found to be generally minor. However, the teams did find damage due to the earthquakes, which could be informative for the future design of port facilities.

At the Port of Kumamoto, movable bridges for the ferries were disabled, which could be attributed to the deformation of ground. Figures 9-12 show one of the disabled movable bridges. The bridge was prepared for the embarkation and disembarkation of vehicles. To deal with large tidal variation, the girder was suspended by two hydraulic cylinders on both sides of the traffic as shown in Figure 9. However, after the earthquake, the vertical movement of the girder was disturbed, and the bridge was out of order. The disturbance was due to the residual displacement of the gate-type structure supporting the hydraulic cylinders, in the direction indicated by the blue arrow in Figure 10.

![Figure 9: One of the disabled movable bridges at the Port of Kumamoto (16 April 2016)](image)

![Figure 10: Direction of residual displacement of the gate-type structure (16 April 2016)](image)

![Figure 11: Details of the disturbance (16 April 2016)](image)
A ‘temporary support’ for use during the maintenance of the hydraulic cylinders existed at the portion indicated by the red circle in Figure 9. A bird’s-eye view of this portion from the girder is shown in Figure 11. The hook fixed to the girder (Figure 11) was designed to go through the small space in the temporary support. However, due to the earthquake, the temporary support fixed to the gate-type structure was subject to residual displacement up to 8 cm, thus disturbance occurred.

Actually, the residual deformation of the ground played a key role in this case. Figure 12 shows the foundation of the bridge. The gate-type structure was supported by piles embedded in a slope as shown in Figure 12. During the earthquake, downslope residual displacement of ground occurred, resulting in the residual displacement of the gate-type structure and the disturbance of the movable bridge. This was a typical case of the residual deformation of the ground affecting the performance of the whole structure.

Figure 12: Foundation of the movable bridge

3.2 Outline of Performance Verification of Port Structures

In the earthquake-resistant design of port structures in Japan, close attention is paid to the residual deformation of ground. In this section, the outline of typical performance requirements and performance verification of port structures is described, for the case of a gravity-type quay wall, referring to the technical standard.

For the L1 ground motion, ordinary functions of quay walls shall be maintained. For the L2 ground motion, particular functions expected for seismic-resistant quay walls after an earthquake shall be recovered within a designated period of time. In the case of a seismic-resistant quay wall with higher seismic resistance, particular functions expected for the quay wall after an earthquake shall be maintained. Seismic resistant facilities can be categorised as Table 1 in terms of functions expected after an earthquake and the period in which the functions should be recovered.
Seismic resistant facilities

<table>
<thead>
<tr>
<th>Special</th>
<th>Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>for emergency transportation</td>
<td>for main-line transportation</td>
</tr>
<tr>
<td>for emergency transportation</td>
<td>for emergency transportation</td>
</tr>
</tbody>
</table>

Functions expected after the action of L2 ground motion

- can be used for mooring, passenger transportation and emergency cargo transportation immediately after the action of the L2 ground motion
- can be used for main-line transportation within a short period of time after the action of the L2 ground motion
- can be used for mooring, passenger transportation and emergency cargo transportation within a certain period of time after the action of the L2 ground motion

- particular functions after an earthquake
- ordinary functions
- particular functions after an earthquake

Allowable amount of restoration work

- slight restoration work
- slight restoration work
- a limited amount of restoration work

**Table 1: Categorisation of seismic resistant facilities**

A recommended procedure for the performance verification of a gravity quay wall is shown in Figure 13. Performance verification for the L1 ground motion can be carried out with a pseudo static approach. Performance verification of seismic-resistant quay walls for the L2 ground motion should be carried out with a detailed dynamic analysis.

It should be noted that the failure modes assumed in the pseudo-static approach, such as sliding or overturning, are not necessarily consistent with actual failure modes observed in the past case histories. For example, field investigations at the Port of Kobe after the 1995 Hyogo-ken Nanbu earthquake (M,7.3) revealed that, although the caisson quay walls exhibited several metres of horizontal displacement, no significant relative displacement was found between the caisson and the rubble mound, i.e., the horizontal displacement of the caisson was mainly caused by the shear deformation of the rubble mound and/or the underlying ground [Inagaki et al., 1996]. This result of field investigation is consistent with the results of shake table tests and effective stress analyses [Inagaki et al., 1996]. Taking these observations into account, the pseudo static approach in the technical standard is designed to determine a cross section of a gravity quay wall which satisfies the criteria in terms of horizontal displacement (typically 10 cm).

The performance of seismic-resistant quay walls of gravity type for the L2 ground motion is most typically evaluated with a two-dimensional effective-stress finite element analysis. In the performance verification of port facilities, the decrease of effective stress in the ground due to the excess pore water pressure is not negligible in many cases. The decrease of effective stress leads to a change in the stress-strain relation and the damping characteristics of the soil. To take into account these effects appropriately, effective stress analyses are required.

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1 This means the allowable amount of restoration work before temporary use after the earthquake.
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5 REFERENCES


**SUMMARY**

The technical standard for port facilities in Japan went through a major revision in 2007 and 2018. One could point out two remarkable features of the recent earthquake resistant design of port structures in Japan: One is that it is based on site-specific design ground motions; both L1 and L2 design ground motions are evaluated with considerations of the source, path and site effects. To achieve the quality control of design ground motions, the technical standard encourages temporary in-situ earthquake observation at the site for construction. The other remarkable feature is that it pays close attention to the residual deformation of ground; quantitative evaluation of the deformation of a soil-structure system is included as part of the design procedure. The purpose of this article is to describe these two essential aspects of the earthquake resistant design of port structures in Japan.

Generally speaking, strong ground motions are determined by three effects, namely, the source effect, the path effect and the site effect. Among these, the site effect is defined as the effect of sediments below the site down to the bedrock. The existence of sediments below the site has significant effects on the amplitude, frequency content and duration of strong ground motions. Thus, evaluation of the site effect is fundamentally important to predict strong ground motions from future large earthquakes and to determine design ground motions. Examples of the site effects in Japan are introduced in the article. There are several methods to generate site-specific design ground motions. In this article, the method based on site-specific amplification and phase characteristics is described.

The performance of port structures subject to earthquake ground motions is significantly affected by the residual deformation of ground. Case histories encountered during the reconnaissance activities for the 2016 Kumamoto earthquake sequence recalled this principle. The 2016 Kumamoto earthquake sequence hit Kumamoto and Oita prefectures, Kyushu, Japan, with the largest event of M7.3. At the Port of Kumamoto, movable bridges for the ferries were disabled, which could be attributed to the deformation of ground. The bridges were prepared for the embarkation and disembarkation of vehicles. To deal with large tidal variation, a girder was suspended by two hydraulic cylinders on both sides of the traffic. However, after the earthquake, the vertical movement of the girder was disturbed, and the bridge could not be used. Actually, the residual deformation of the ground played a key role in this case. The structure was supported by piles embedded in a slope. During the earthquake, downslope residual displacement of ground occurred, resulting in the residual deformation of the structure and the disturbance of the movable bridge. This was a typical case of the residual deformation of the ground affecting the performance of the structure.

De manière générale, les forts séismes sont définis par trois effets, à savoir l’effet source, l’effet de trajectoire et l’effet de site. Parmi ceux-ci, l’effet du site est fonction de la nature des sols entre la surface et le substrat rocheux. L’existence de sédiments sous le site a des effets significatifs sur l’amplitude, la fréquence et la durée des séismes. Par conséquent, l’évaluation de l’effet du site est d’une importance fondamentale pour prévoir les forts mouvements du sol lors de futurs grands séismes et pour définir les séismes de projet. Des exemples de définitions d’effets de site au Japon sont présentés dans l’article. Il existe plusieurs méthodes pour concevoir des séismes de projet adaptés aux sites. Dans cet article, la méthode décrite se base sur les caractéristiques d’amplification et de déphasage spécifiques au site.

La performance des infrastructures portuaires après un séisme est fortement affectée par la déformation résiduelle du sol. Le retour d’expérience établi après le séisme de Kumamoto 2016 l’ont confirmé. Le développement du séisme de 2016 à Kumamoto a frappé les préfectures de Kumamoto et d’Oita (Kyushu, Japon), avec une magnitude atteignant 7.3. Au port de Kumamoto, les passerelles roro du terminal ferry ont été rendues inopérantes à cause de la déformation du sol. Les passerelles ont été conçues pour l’embarquement et le débarquement des véhicules. Pour prendre en compte la variation de niveau importante due aux marées, le tablier est déplacé de part et d’autre. Après le séisme, le mouvement vertical du tablier a été perturbé et la passerelle n’a plus pu être utilisée. Dans ce cas, la déformation résiduelle du sol a joué un rôle clé. La structure était soutenue par des pieux fichés dans une pente. Après le séisme, on a constaté un déplacement résiduel du sol vers l’aval, qui a entraîné une déformation de la structure et rendu inopérant le pont mobile. Il s’agit d’un cas typique de déformation résiduelle du sol affectant une infrastructure.
erzeugen. In diesem Artikel wird die Methode, die auf der standortspezifischen Verstärkung und den Phaseneigenschaften beruht, beschrieben.


RESUMEN

La normativa técnica dedicada a las instalaciones portuarias en Japón fue objeto de una profunda revisión entre los ejercicios 2007 y 2018. En este escenario, se pueden subrayar dos elementos específicos relativos al diseño de estructuras portuarias en condiciones de sismo, tras las últimas experiencias acaecidas sobre el particular: El primero de ellos es el relativo a los movimientos del suelo en las condiciones locales específicas de diseño; las componentes L1 y L2 se evalúan en función de la fuente, la trayectoria y las condiciones locales. Para alcanzar un adecuado nivel de control de calidad en la definición de los movimientos del terreno, la normativa recomienda la observación de las condiciones locales de la ubicación de la obra. El otro elemento importante es la necesidad de prestar especial atención a las deformaciones residuales que experimente el suelo; la evaluación cuantitativa de la deformación del conjunto suelo-estructura se incluye como parte del procedimiento de diseño. El objeto de este artículo es el de describir estos dos aspectos esenciales para el diseño de las estructuras portuarias sometidas a sismo en Japón.

Con carácter general, los grandes movimientos del suelo están gobernados por tres efectos, denominados efecto fuente, efecto trayectoria y efecto ubicación. De entre éstos, el efecto ubicación se define como el efecto derivado de los sedimentos existentes en el emplazamiento de la obra, hasta llegar al lecho de roca. La existencia de dichos sedimentos tiene gran importancia en la amplitud, frecuencia y duración de los grandes movimientos del suelo. Así, la evaluación del efecto ubicación es especialmente importante a la hora de predecir los movimientos del terreno en condiciones de sismo. Ejemplos en este sentido se citan en el cuerpo del artículo. Existen diversos métodos para valorar este concepto. En el presente artículo se describe el método basado en la amplificación local y las características de fase.

El comportamiento de las estructuras portuarias sometidas a movimientos del terreno inducidos por sismo está singularmente afectado por las deformaciones residuales del suelo. Algunos ejemplos se pueden encontrar en los reconocimientos llevados a cabo tras la serie de terremotos de Kumamoto en 2016. Este episodio golpeó las prefecturas de Kumamoto y Oita con una magnitud máxima de 7,3. En el puerto de Kumamoto las pasarelas móviles para la operativa de ferry quedaron deshabilitadas debido a la deformación experimentada por el suelo. En el caso de las instalaciones destinadas al embarque/desembarque de vehículos, y debido al elevado rango de marea, existía una viga suspendida por dos cilindros hidráulicos, la cual sufrió daños con motivo del terremoto que imposibilitaban su utilización. La deformación residual del terreno jugó un papel fundamental en este hecho. La estructura estaba soportada por pilas empotradas sobre un terreno en talud, el cual sufrió desplazamientos y deformaciones que afectaron decisivamente a la estructura móvil allí ubicada. Se trata de un caso típico de cómo el movimiento residual del terreno afecta al comportamiento de una estructura cimentada sobre él.
INTRODUCTION

The devastating magnitude 9.0 earthquake off the Pacific coast of Tōhoku – the Great East Japan Earthquake – occurred at 14:46 JST on 11 March 2011. The earthquake generated a powerful tsunami, hereinafter referred to as the 2011 Tsunami. Inundation heights in many coastal cities in Iwate and Miyagi prefectures were larger than 10 m and in the coastal Sendai Plain, the tsunami traveled up to 10 km inland. The tsunami caused wide and severe damage to port and coastal facilities, e.g. breakwaters, seawalls, dykes and quay walls.

In this article, the failure characteristics of breakwaters are firstly explained. Then, a new design method based on research conducted after the Great East Japan Earthquake is introduced. Lastly, the restoration of breakwaters in the Tohoku region and Tsunami remedial work outside the Tohoku region is described.

DAMAGE TO BREAKWATERS

Many breakwaters were damaged by the 2011 Tsunami mainly because tsunami loading on breakwaters exceeded breakwater design loads. Tsunami overflow had not been assumed because of the lack of a design formula to express the strong tsunami force occurring during overflow. Here, the failure characteristics of the Kamaishi and Hachinohe Breakwater are explained.

2.1 Kamaishi Breakwater

The Kamaishi breakwater was built to protect Kamaishi City against Tsunamis. Kamaishi City has a long history of tsunami attacks; examples are the 1896 Meiji Sanriku Tsunami, the 1933 Showa Sanriku Tsunami and the 1960 Chilean Tsunami. Construction of the breakwater started in 1978 and was completed in 2008.

The breakwater was designed to reduce the wave height in the port of a Meiji-sanriku-class tsunami from 8 m to 4 m. The design tsunami height (period) of the original breakwater was 5.63 m (16 minutes), which corresponds to the tsunami height (period) of the Meiji Sanriku Tsunami. A second parameter of the design was dampening storm waves induced by typhoons and low-pressure storm systems. The design significant (maximum) wave height is 7.4 m (13.3 m) and the wave period is 13 s [Ohori et al., 1985].

The breakwater, a composite-type as shown in Figure 2, was composed of a north breakwater and a south breakwater (Figure 1).

The breakwater was heavily damaged by the 2011 Tsunami, as shown in Figure 3.
Figure 4 is a bathymetric map of the breakwater made using a narrow multi-beam echo sounder system after the 2011 tsunami. Only 10 of the 22 south-breakwater caissons remained and 7 of the 44 north breakwater caissons were displaced toward port. The caissons at the mouth of the breakwater were also displaced toward port.

**Figure 1: The Kamaishi Breakwater**

**Figure 2: Schematic drawing of the Kamaishi Breakwater**

**Figure 3: Failure of the Kamaishi Breakwater**
The height of the 2011 tsunami at the breakwater was 11.3 to 12.4 m, much higher than the design tsunami height and the tsunami overflowed the caissons as shown in Figure 5. The difference in water level between the front and rear of the caisson imposed enormous tsunami pressure on the caissons causing them to be displaced. As will be mentioned later, a design formula to express tsunami pressure during overflow was not available when the breakwater was designed.

Though heavily damaged, the diminished tsunami height in Kamaishi city from 13 m to 7 to 9 m delayed its attack time by 6 minutes.

2.2 Hachinohe Breakwater

The Port of Hachinohe was protected by three large breakwaters: the north breakwater, the central first breakwater and the central second breakwater (Figure 6). Of the three, the north breakwater was heavily damaged by the 2011 tsunami (Figure 7).

The north breakwater was composed of 19 sections. Many caissons from the 11th to the 13th section and all caissons except the head (Figure 8), from the 16th section to the 19th section, were displaced.

The design wave height from the 16th section to the 19th section was lower than other sections because of the wave angle. Tsunami overflow on the breakwater was recorded by video cameras. The design wave height and width of caissons from the 16th to the 19th section were smaller than at other sections because of the wave angle. The strong tsunami loading on the breakwater was due to the difference in the water level between the front and rear of caissons, which caused sliding displacement of the
caissons. In contrast, from the 11th section to the 13th (Figure 9), it was clarified by the bathymetrical survey that scour in the sandbed behind the breakwater caused the sliding displacement of caissons. In the Port of Hachinohe, large scour occurred around the structures. In Figure 6, dotted circles show the scour depth around the structures.

![Figure 6: The Port of Hachinohe and the breakwater [Tomita et al., 2012]. Dotted circles show the scour depth around the structures.](image1)

Figure 7: The north breakwater and the damage [Tomita et al., 2012]

Figure 8: Head of the north breakwater. Only the head was remained.

Figure 9: Collapse of the breakwater
3 INVESTIGATION OF THE CAUSE OF TSUNAMI DAMAGE

After the 2011 Tsunami, MLIT (Ministry of Land, Infrastructure, Transport and Tourism), PARI (Port and Airport Research Institute), JSCE (Japanese Society of Civil Engineers) and other organisations conducted field investigations on inundation heights and areas and damage to port and coastal facilities. Hydraulic experiments were also conducted, as depicted in Figure 10 and 11. [Arikawa et al., 2012; 2013]

![ Figure 10: Experimental study on the Kamaishi Breakwater [Arikawa et al., 2012] ]

![ Figure 11: Experimental study on the Hachinohe breakwater [Arikawa et al., 2013] ]

4 EVOLUTION OF THE DESIGN METHOD

After the 2011 Tsunami, guidelines for breakwaters and guidelines for inland parapets were published in 2013. In the guidelines, tsunami levels (L1, L2 tsunami and design tsunami) and tsunami pressure formulas were introduced. Tenacious structures to resist tsunami forces were introduced as well.

4.1 L1 and L2 Tsunami

In the guideline for breakwaters, two new levels of tsunami were introduced. A Level 1 (L1) tsunami is a ‘frequently-occurring tsunami’ whose recurrence interval is 10 to 100 years. A Level 2 (L2) tsunami is a ‘maximum-class tsunami’ whose recurrence interval is about 1000 years. The design for tsunami loads
on coastal structures is determined to be between L1 and L2 tsunami as shown in Figure 12. In many cases, the L1 criteria are used for tsunami-resistant design.

\[ H_{L1} \leq H_{\text{Design}} < H_{\text{Larger than design}} \leq H_{L2} \]

4.2 Tsunami Pressure (Force) Formula

Based on hydraulic experiments, a tsunami pressure (force) formula was introduced and added to the existing Tanimoto tsunami pressure formula.

4.2.1 Tanimoto’s Pressure Formula

Tanimoto’s pressure formula was established after the 1983 Central Sea of Japan Earthquake and Tsunami based on hydraulic experiments. [Tanimoto et al., 1983]

\[ \eta^* = 3.0a_i \quad (1) \]

\[ p_1 = p_u = 2.2\rho_0ga_i \quad (2) \]

\[ p_2 = p_L = \rho_0g\eta_B \quad (3) \]

where, \( \eta^*(m), \eta_B(m), a_i(m), p_1(kN/m^2), p_u(kN/m^2), p_2(kN/m^2), p_L(kN/m^2) \) are expressed as shown in Figure 13 and \( \rho_0g \) (kN/m^3) is the specific weight of seawater.
4.2.2 Modified Tanimoto Pressure Formula

When the front end of a tsunami is a breaking bore state and it impinges upon a vertical wall, the pressure is possibly much larger than the original Tanimoto formula. Ikeno et al. (2005) conducted a series of hydraulic experiments that clarified this phenomenon. Based on experimental results, Tanimoto’s formula was modified as equation (4) instead of equation (2) to express the breaking bore pressure.

\[ p_1 = p_u = 3.0 \rho_0 g a_t \] (4)

4.2.3 Pressure Formula During Tsunami Overflow

The Kamaishi breakwater was damaged by the strong force of the tsunami overflow. During tsunami overflow on a caisson, a pressure difference between the front and rear sides of the caisson arises and applies a large force on the caisson. Based on experimental results, a new pressure formula that takes tsunami overflow account was introduced as equation (5) to (7).

\[ p_1 = \alpha_f \rho_0 g (\eta_f + h') \] (5)
\[ p_2 = (\eta_f - h_c) p_1 / (\eta_f + h') \] (6)
\[ p_3 = \alpha_r \rho_0 g (\eta_r + h') \] (7)

where, \( \eta_f (m), \eta_r (m), h' (m), h_c (m), p_1 (kN/m^2), p_2 (kN/m^2), p_3 (kN/m^2) \) are expressed as shown in Figure 14 and \( \rho_0 g (kN/m^3) \), \( \alpha_f, \alpha_r \) are the specific weight of seawater and modification factors for hydrostatic pressure (5) and (6) respectively.

In the original guidelines (2013), modification factor \( \alpha_f, \alpha_r \) decided as 1.05 and 0.9 respectively according to the experimental results of Arikawa et al. (2012). However, when the water level behind the caisson is extremely low, the modification factor \( \alpha_r \) scatters. To express the modification factor across wider conditions, a new estimation method was proposed by Tsuruta et al. (2016). In addition, the relationship of buoyancy and uplift force was investigated by Suzuki et al. (2017).

![Figure 14: Schematic drawing expressing pressure formula during tsunami overflow](image)

4.3 Safety Factor and Tenacious Structure

4.3.1 Design Tsunami

Structures must resist the design tsunami criteria. Using the pressure formula described previously, stability for sliding, overturning and bearing capacity can be checked. Safety factors for sliding displacement, toppling and bearing capacity are set as 1.2, 1.2 and 1.0, respectively.
4.3.2 Tsunami Larger Than Design Tsunami

Even for tsunamis larger than the design tsunami, a structure must minimize failure due to tsunami loads to be ‘tenacious’. If the tsunami is larger than the design tsunami, structures are likely to have weak points. For example, if a tsunami is extremely large and the safety factor for sliding displacement is less than 1.0, then the sliding mode is the weak point of the structure. In this case, even if the structure is damaged, at least the total failure of the structure should not occur during tsunami attack. To be structurally tenacious, a structure’s weak points have to be reinforced.

5 RESTORATION OF BREAKWATERS IN THE TOHOKU REGION

5.1 Kamaishi Breakwater

The caissons displaced by the 2011 tsunami were removed using a rock-breaking hammer and large grab bucket for hard rock. 37 of the 44 caissons of the north breakwater and 12 of the 22 caissons of the south breakwater were removed.

The restored breakwater was designed in accordance with the new design guidelines for breakwaters. It is not only designed to resist design tsunami loads and effects but also be resistant to the tsunami larger than design tsunami. The safety factor against a level 2 tsunami was set as 1.1.

To make the breakwater tenacious, a friction-increasing asphalt mat was installed under the new caissons. To make the caissons tenacious, an additional rubble mound was installed behind the caissons. Restoration of the Kamaishi breakwater was completed in March 2018 (Figure 15).

5.2 Hachinohe Breakwater

The restored breakwater was designed to resist scour by tsunami overflow. Improvement in the shape of the crown concrete, shown in Figure 16, diverts tsunami overflow away from the caisson, preventing scour in the sandbed. The improved caisson shape represents one of the methods by which tenacious structures against tsunami are being achieved.

Aside from Kamaishi breakwater improvements, the displaced caissons of the Port of Hachinohe breakwater were also removed using a rock-breaking hammer and large grab bucket for hard rock.

![Figure 15: Restoration of the Kamaishi breakwater](image-url)
6 TSUNAMI REMEDIAL WORK OUTSIDE THE TOHOKU REGION

It is likely that large tsunamis will attack regions outside the Tohoku region in the future.

The Nankai megathrust earthquakes have a recurrence interval of about 90-200 years, and often occur in a parallel manner with a Tonankai earthquake. Because Japan’s population is concentrated along the Pacific Ocean side of the country, future Nankai earthquakes with accompanying threats to human life and infrastructure are anticipated. Kochi Prefecture is a high-risk area likely to be attacked by a severe tsunami in the future.

Along the Kochi coastline, the construction of tsunami defenses (breakwaters, seawalls, dikes, and other protective structures) is proceeding. Figure 17 shows the tsunami defense zone of Kochi Prefecture. The city of Kochi is located inside Urado Bay.

Because a tsunami is expected to inundate areas inside the bay similar to the inundation induced by the 1946 Tsunami, three lines of protection are planned to prevent tsunami intrusion. The 1st line of protection is composed of breakwaters. Dikes, seawalls and a new tsunami breakwater around the mouth of Urado bay comprise the 2nd line of protection. And dikes and seawalls inside Urado bay form the 3rd line of protection.

Considering the subsidence of the breakwater due to crustal movement and the enlarged design tsunami height, crown heights of the breakwaters were increased in the new design and to stabilise caissons an additional rubble mound was installed.

Figure 17: Kochi tsunami defenses (a triple-zone of protection)
7 CONCLUSIONS

In this article, tsunami researches on breakwaters after the Great East Japan Earthquake was referred. The failure characteristics of breakwaters are firstly explained. At Kamaishi Port, the difference in water level between the front and rear of the breakwater’s caisson imposed enormous tsunami pressure on the caissons causing them to be displaced. At Hachinohe Port, a severe scour behind the breakwater occurred due to overflowing tsunami, resulting in the sliding of the caisson. To clarify these breakwaters’ failures, a series of hydraulic experiments were conducted. Then, a new design method including a new tsunami pressure formula was established, and a new design guideline of breakwaters against tsunami was published. Lastly, the restoration of breakwaters in the Tohoku region and Tsunami remedial work outside the Tohoku region were described.

8 REFERENCES


SUMMARY

The devastating magnitude 9.0 earthquake off the Pacific coast of Tōhoku occurred at 14:46 JST on 11 March 2011. The earthquake generated a powerful tsunami. Inundation heights in many coastal cities in Iwate and Miyagi prefectures were larger than 10 m and in the coastal Sendai Plain, the tsunami traveled up to 10 km inland. The tsunami caused wide and severe damage to port and coastal facilities, e.g. breakwaters, seawalls, dykes and quay walls.

In this article, the failure characteristics of breakwaters are firstly explained. The Kamaishi Breakwater collapsed due to the extremely large tsunami force. The difference in water level between the front and rear of the caisson imposed enormous tsunami pressure on the caissons causing them to be displaced. The north breakwater of the Port of Hachinohe slid and overturned due to the scour in the sandbed behind the breakwater. Therefore, a new design method based on research conducted after the Great East Japan Earthquake is introduced. Based on hydraulic experiments, a tsunami pressure (force)
formula was introduced and added to the existing tsunami pressure formula. The new tsunami levels (Level 1, Level 2 tsunami; design tsunami and tsunami larger than design tsunami) for the design of coastal facilities were also introduced. Tenacious structures to resist a tsunami larger than the design tsunami were also introduced. Lastly, the restoration of breakwaters in the Tohoku region and Tsunami remedial work outside the Tohoku region are described.

RESUME

Le séisme d'une magnitude de 9,0 survenu sur la côte pacifique de la province de Tōhoku s'est produit le 11 mars 2011, à 14h46 JST. Le séisme a généré un puissant tsunami. La hauteur des vagues dans de nombreuses villes côtières des préfectures d'Iwate et de Miyagi était supérieure à 10 m. Dans la plaine côtière de Sendai, le tsunami est entré sur 10 km à l'intérieur des terres. Le tsunami a provoqué de graves dégâts dans les installations portuaires et côtières, tels que les brise-lames, digues maritimes, jetées et murs de quai.

Dans cet article, les caractéristiques de rupture des digues sont d'abord expliquées. Le brise-lames de Kamaishi s'est effondré en raison de la force extrêmement importante du tsunami. La différence de niveau d'eau entre l'avant et l'arrière du caisson leur a appliqué une énorme pression, provoquant leur déplacement. Le brise-lames nord du port de Hachinohe a glissé et s'est renversé à cause de l'affouillement du sable à l'arrière du brise-lames. Les recherches menées après le grand séisme survenu au Japon oriental ont permis de définir une nouvelle méthode de conception.

Sur la base d'expérimentations hydrauliques, une formule introduisant la pression de tsunami (force) a été ajoutée à la formule de calcul initiale. La conception des infrastructures côtières utilise maintenant de nouveaux niveaux de tsunami (tsunami de niveau 1, Tsunami de niveau 2; tsunami de projet et tsunami plus grand que le tsunami de projet). Des structures robustes destinées à résister à un tsunami plus grand que le tsunami de projet ont également été conçues. Enfin, la restauration des digues dans la province et les travaux de remise en état hors de la province de Tōhoku après le tsunami sont décrits.

ZUSAMMENFASSUNG


RESUMEN

Un devastador terremoto de magnitud 9,0 golpeó la costa pacífica de Tōhoku a las 14:46 horas del 1 de marzo de 2011, generando un gran tsunami. Las inundaciones en varias ciudades costeras de las prefecturas de Iwate y Miyagi superaron los 10 m, y en la costa de Sendai el agua penetró hasta 10 km hacia el interior. El tsunami provocó daños severos en múltiples estructuras costeras, tales como diques, obras de defensa, muelles, etc.

En este artículo se muestra una primera explicación de las características de los fallos experimentados por los diques. El dique de Kamaishi colapsó debido a las solicitudes generadas por el efecto del tsunami. La diferencia del nivel de agua entre trasdós e intradós de los cajones produjo fuerzas sobre los mismos que generaron desplazamientos. El dique Norte del puerto de Hachinohe deslizó y volcó debido a la socavación del lecho de arena que afectó a la zona trasera de la estructura. Como consecuencia de todo ello, se introduce un nuevo método de diseño basado en las experiencias derivadas del gran terremoto del Este de Japón. Derivada de ensayos hidráulicos, se propone una formulación para el cálculo de las presiones (fuerzas) producidas por el tsunami. También se introducen los nuevos niveles de tsunami (L1 y L2; tsunami de diseño y tsunami superior al de diseño) para el diseño de las instalaciones costeras. La robustez de las estructuras para poder resistir episodios superiores al Tsunami de diseño es un concepto que se analiza. Y finalmente se describen los trabajos de reconstrucción de diques, dentro y fuera de la región Tohoku.
1 INTRODUCTION

In order to cope with climate change, the Paris Accord which was concluded at the 2015 United Nations Framework Convention on Climate Change Conference of the Parties raised gas emission totals for all countries and decided to press forward with early stage carbon reduction.

In our country as well, there are plans for the expanded use of energy with thorough promotion of energy conservation and smaller environmental burdens toward the transition to a low-carbon society. Furthermore, in the future it is assumed that there will be expanded use of new energy such as hydrogen.

In this paper we will examine efforts with consideration for the environment in our country and the field of ports, mainly speaking on specific examples in the field of port logistics.

2 SUMMARY OF EFFORTS

2.1 Efforts in Our Country Overall

The world population has exceeded 7 billion people, and in 2050 it is expected to reach 9.8 billion people. Burdens to the Earth's environment caused by human activities continue to increase, and the continuation of the Earth's environment which is the foundation of human existence is on the verge of danger. With this sense of crisis in mind, the 'Sustainable Development Goals (SDGs)' and the 'Paris Accord' were adopted in 2015.

In order to achieve the goals of the Paris Accord, total emission volumes considering sink measures must be reduced to below a certain volume, and in our country as well it is necessary to continuously promote the prompt reduction of greenhouse gases based on the ideal useable science. As a part of our country's response to the Paris Accord, we established a Global Warming Countermeasure Plan based on the Law Concerning the Promotion of the Measures to Cope with Global Warming (1998 Law No. 117) in May 2016. In this plan, the mid-term goal for 2030 was to reduce greenhouse gas exhaust by 26 % compared to 2013, and the long-term goal was “Our country, with consideration for the Paris Accord and under fair and effective international efforts joined by all major emitting countries, will lead the international society in efforts to reduce emissions by said major emitting countries, while also maintaining a balance of measures against global warming and economic growth, aiming for an 80-% reduction in emissions by 2050 as a long-term goal. Such drastic emissions reductions will be difficult by extending existing efforts. Therefore, while pursuing the development and proliferation of innovative technologies which enable drastic emission reductions, and in order to promote domestic investment, increase international competitiveness, and wisdom sought broadly for the citizens, as well as striving for drastic emissions reductions in long-term and strategic efforts and contribute to reductions in the
world at large”. Our country is proceeding towards the achievement of the long-term goal based on the Global Warming Countermeasure Plan, and in 2016, the overall greenhouse gas emission volume was 1,307 billion tonnes of CO₂. Comparing the total emissions (1,323 billion tonnes of CO₂) of the previous year (2015) with the total emissions of 2013, due to the reduction in emissions from CO₂ energy sources accompanying expanded adoption of renewable energy, reopening of nuclear plants, etc., emissions were reduced by 1.2 % over the previous year and by 7.3 % in 2013. Moreover, in addition to aiming for a drastic reduction in CO₂ emissions domestically, we will be contributing as much as possible to reducing emissions throughout the world and advance efforts which will lead to further economic growth in our country.

2.2 Port and Harbour-Related Efforts

Accepting and applying the Paris Accord, it is necessary to advance efforts to reduce greenhouse gases, etc. in our country as well. In particular with regard to wind energy, which is a form of renewable energy which greatly contributes to the reduction of greenhouse gases, considering the fact that stable energy can be provided there is an increased demand for deployment offshore, as well as a demand for the effective utilisation of ports and other water regions. On 3 July 2018, the 5th ‘Basic Energy Plan’ was approved by the Cabinet, where basic policies on energy measures were established, such as the proactive application of renewable energy sources like wind energy and hydrogen energy, as well as the promotion of preparing systems and R&D to achieve these goals.

Furthermore, according to the International Maritime Organisation (IMO), after 2020, in accordance with the decision to strengthen the regulated limit for sulfur content in the general sea area (currently 3.5 % or less) to 0.5 % or less, it will be necessary to conduct more stringent environmental consideration in the field of maritime affairs as well such as switching to LNG to propel ships.

Moreover, following the adoption by the UN of the SDGs which are the development goals of international society at large by 2030, it has become standard to look not only at cost but also at sustainability by company supply chain management. For this reason, at ports in our country, in addition to improving the safety of ship navigation, we will strive to apply advanced environmental technologies and accelerated response to create competitive differences with other countries and ports.

In order to respond responsibly to environmental issues at ports, we are moving toward greater adoption of sea wind power generation, reduced carbon in ships, cargo-handling machineries and trailers, as well as the adoption of land power supply equipment. We will seek to reduce CO₂ emissions through application of blue carbon ecosystems (seaweed, etc.), which effectively utilise industrial by-products such as iron and steel slag. By advancing these efforts, we will aim to realise the world’s first ‘carbon-free port’.

In addition, we will utilise our world-leading environmental innovation and the geographical advantage of our ports in order to promptly respond to ship fuel changes, etc. that are expected due to strengthened environmental regulations in the field of maritime affairs in order to promote ships stopping at our ports. Our country has imported the most LNG in the world and has many LNG bases located in major harbours, having developed an LNG network in cooperation with Singapore. We are aiming to construct an international LNG bunkering base together with a support system for facility maintenance.

Furthermore, in order to secure the navigation and safety of ports and routes, we will expand environmental reception procedures to promote ships berthing which are currently being adopted at major ports as well as broadening of routes, securing of harborage locations, etc.

3 CARGO MACHINES SWITCHING TO ELECTRICITY

3.1 Summary

Container terminal loading work is mainly divided into ship-to-shore loading/unloading and carry out loading/unloading, each of which are performed with particular cargo-handling machinery. While ship-to-shore cranes are already powered by electricity, but the electrification of transfer cranes which load and unload in yards, especially, RTGs (Rubber Tire Gantry crane), which run on rubber tires, has not advanced. RMGs (Rail Mount Gantry), another kind of transfer cranes running on a rail, has been almost electrified.
RTGs are generally run by an engine which burns diesel to generate the power necessary to move the unit and load containers. However, the amount of fuel (oil) it uses is comparatively large, and it requires time to supply fuel. In addition, it is subject to operating time restrictions due to periodic maintenance of the engine. The biggest problem, however, is its large environmental burden by emitting CO$_2$, NOx, etc. If RTGs were to use an external power source instead of the existing power generators, cost reductions, optimisation of handling operations and a decrease in the environmental burden could be realised.

3.2 Power Supply Methods

The electrification of RTGs generally takes place using the following methods, but in our country the bus bar method which possesses the following benefits is utilised.

Benefits of the bus bar method:
1. Lane change is possible
2. Multiple RTGs can be deployed on a single lane
3. Possible to reform while operating terminal
4. RTG can load and unload even during electric outages or with limited power
5. Capable of prompt restoration of above-ground facilities during disasters, etc.

(Examples of RTG electricity supply methods)

a) Pantograph Method

A method which has wiring in a higher location than the RTG, supplying electricity from the top of the RTG.

![Figure 1: Pantograph](image)

b) Cable Reel Method

Installing a cable car on an RTG and using the cable to supply electricity to the RTG unit through the cable by reeling the cable in or out when moving.
c) Bus Bar Method

A trolley line called a bus bar is installed which supplies electricity to the RTG main unit. Furthermore, because bus bars are secured about 2 m above ground, normally they use a frame installed in the pavement of a yard, but in this case considerable restoration work would be required when braces change shape due to large-scale earthquakes. Therefore, by placing a joint block on the ground surface and installing the frame there, this method is utilised to enable the installation and repositioning of the yard without the removal or pounding of the pavement. By doing so it is possible to operate with the smallest influence on the container terminal, while also enabling easy restoration after disasters, etc.
3.3 Reduced Environmental Burden

Based on the inspection results, the amount of CO\textsubscript{2} produced was reduced by 1,226 t in 12 months, for about a 30% reduction. The amount of NOx produced was reduced by 4.5 t in 12 months, for about a 42% reduction.

![Figure 6: Amount of CO\textsubscript{2} emitted per month (RTG total amount)](image)

![Figure 7: Amount of NOx emitted per month (RTG total amount)](image)

4 LAND POWER SUPPLY

4.1 Summary

Land power supply refers to something called ‘AMP’ (Alternative Maritime Power), the purpose of which is to prevent air pollution through the reduction of carbon dioxide and gas emissions by stopping the onboard auxiliary engine (diesel generator) which the ship requires while berthing and supplying electricity from commercial power supply. It was first used in places like California in the US with its severe atmospheric environment and Sweden, where the effect of SOx (sulfur oxide) is considerable.

The frequency of the onboard electricity is normally 60 Hz, whereas land power is 60 Hz in the United States but usually 50 Hz in Europe, 60 Hz in West Japan and 50 Hz in East Japan. In 50-Hz regions, it is a problem because it requires frequency conversion when supplying power.
4.2 Efforts Within Japan

Land power while berthing is already being used in Japan by the US Forces, as well as the dredgers possessed by the Ministry of Land, Infrastructure, Transport and Tourism.

Furthermore, we conducted a demonstration experiment on the cargo-passenger ship Salvia Maru (4,964 t) from October 2006 in Takeshiba Wharf and in 2008 formed the ‘technological inspection committee for land power supply for ships’. We also conducted trials at 3 ports around the country to identify technical problems and studied the standard specifications of land power systems and facility and equipment for various types of ships.

4.3 Demonstration Experiment in Tomakomai Port

The three ports where trials were conducted in 2008 were all in West Japan, where no frequency conversion was required, so from 2009 we also investigated the following points which had not yet been made clear at Tomakomai Port.

- In a 50-Hz region and cold and snowy region
- A 1,000-kW device targeting one of the largest-scale (15,000 GT) ferries in Japan
- All-purpose supply method utilising a chassis which does not require major modification
- Frequency conversion with uninterruptable power connection and 1,000 kW grade EFC (Electric Frequency Converter)

4.3.1 Connection Experiment Details

Targeting the ferry ‘Kiso’, owned by Taiheiyo Ferry Co., Ltd. (see Figure 9) 15,795GT, we conducted the demonstration experiment while berthing at No. 2 Ferry Pier in Tomakomai Port.
In the demonstration experiment, the ships are regular service. Therefore, in order to reduce the obligation on the ship’s side as much as possible, as shown in Figure 10, we used chassis equipped type with almost no modifications on the ship side, and furthermore placed a restriction on the 1,300 kW required due to it being a demonstration experiment and conducted the experiment with 800 kW.

The major characteristics were as follows.

- We used uninterruptable power to avoid the need for reconfiguring the meters and reinitializing the electric equipment of the guest rooms, etc.
- Due to it being a cold and snowy region and considering the operability, we used high voltage 6,600 V and connected inside the ship.
- Furthermore, we designed it with cold region specifications such as snow damage prevention on the connection box and air conditioning for the various machinery.
- Because East Japan is a 50-Hz region, we supplied the power through a frequency converter to 60 Hz.
- We utilised an EFC (electrostatic frequency converter) with high conversion efficiency.

We gathered the following data from the connection experiment and validated the system:

- Switch procedure and electrical behavior in uninterrupted switch
- Electrical behavior of frequency conversion device
- Safety measures in high voltage device
- Functions of power receiving equipment for ships
- Operability of cable connection
- Special qualities of land power in cold regions
- Air quality, emitted gas and noise measurement

5 HYBRID STRADDLE CARRIER

5.1 Summary

Currently, the effective use of energy and efforts toward protecting the earth's environment are recognised as vital issues, and in container terminals there is a great need to conserve energy and reduce CO₂ emissions. Therefore, there is also a demand to improve the energy-efficient and safety of the cargo machines used on site as well.

In order to meet such needs, hybrid straddle carriers which enable drastic fuel reduction compared with traditional machines are being developed and adopted.
5.2 Hybrid System

A hybrid type straddle carrier achieves drastically reduced fuel consumption and CO\textsubscript{2} emissions compared to traditional machineries through the use of a lithium ion battery which essentially allows the machine to be operated as a hybrid system in which both the engine generator and electricity are used.

The hybrid system which is the core of this recharges recycled energy that is generated into a battery when lowering and decelerating and re-uses the energy when hoisting and travelling.

Furthermore, the RPM variation of the engine allows the minimum required power to be used which results in a 25\% reduction in fuel consumption compared to existing machines.

5.3 Effects on the Environment

Along with the reduced fuel consumption, the hybrid straddle carrier emits 15\% less CO\textsubscript{2} compared to existing machines.

6 ROOFED POWER-SAVING REEFER FACILITIES

The roofed power-saving reefer facility installed in Island City on the Port of Hakata is designed to create ‘shade’ by installing a roof onto the reefer containers to control the rise in temperature of the side surfaces, thereby aiming to reduce power consumption.
The facilities depicted in Figure 14 have roofs on the west side of 2 bays but no roofs on those of the east side.

In the roofed area, the surfaces of containers placed on the south side are hit by sunlight, while those on the north side are not, which means that energy consumption of the south side containers tends to be high. In addition, the containers on the West side of 13 bay roofed area are affected by the setting sun, and because this is the refrigerator part of the reefer containers, the power consumption tends to be high even with a roof.

We have come to understand the above tendencies, but other factors are also in play such as the individually set temperatures of the containers, how they are stacked, whether they are new or old, their type of refrigerators, etc.
It is extremely difficult to verify the effects under operation, so we are currently searching for accurate verification methods.

![Figure 15: Power transition of covered power-saving reefer facilities](image)

**Figure 15: Power transition of covered power-saving reefer facilities**

![Figure 16: Comparison of transitions in power for roofed and unroofed facilities](image)

**Figure 16: Comparison of transitions in power for roofed and unroofed facilities**

### 7 CONCLUSION

The report published on 8 October of this year by IPCC pointed out that global warming was causing sea levels to rise, storms to intensify, and poverty to worsen. The air temperature is already almost 1°C higher compared to before the industrial revolution, and at that rate by 2100 it is expected to be 3°C higher. This amounts to twice the pace pointed out in the 2015 ‘Paris Accord’.

For the sake of sustainable development around the world in the future, is it essential that port and harbour shipping departments also proactively proceed with efforts such as advancing cargo-handling machineries (electrification, etc.), optimising logistics/cargo (reduction of repetitive work utilising AI, etc.), making effective use of facilities (preventative maintenance, etc.), adopting clean energy sources, and other efforts.

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SUMMARY

To comply with the Paris Accord, it is necessary to advance efforts to reduce greenhouse gases, etc. in Japan. For this reason, at ports in our country, in addition to improved safety for ship navigation, it will be necessary to apply advanced environmental technologies in order to create competitive differences with other countries and ports. In this paper we will examine efforts being made to enhance the environment in our country, mainly focusing on specific examples in the field of port logistics.

For example, RTG is usually run by an engine which burns diesel to generate power, using electrical power to move the unit and load containers, but a conventional RTG has the following problems: it uses a comparatively large amount of fuel (oil), it requires time for supplying fuel, it is subject to operating time restrictions due to periodic maintenance of the engine, and it has a large environmental burden by emitting CO$_2$, NOx, etc. Therefore, by using an external power source instead of an RTG's generator, cost could be reduced, cargo work time could be optimized, and the environmental burden could be reduced etc.

We conducted trial experiments on cargo-passenger ships at 3 ports around the country from October 2006 which were overseen by the 'technological inspection committee for land power supply for ships'. Based on the trial results, we were able to identify technical issues and prepare standard specifications of land power systems, facilities and equipment at lower costs for various types of ships.

Recently, there has also been a demand to conserve more energy and enhance the safety of cargo handling machines used in container terminals as well. In order to meet such needs, hybrid straddle carriers which enable drastic fuel reduction compared with traditional machines are being developed and adopted.

The roofed power-saving reefer facility has also been designed to create 'shade' by installing a roof onto the reefer containers to control the rise in temperature of the side surfaces of the reefer containers, thereby aiming to reduce power consumption.

The air temperature is already almost 1°C higher compared to before the industrial revolution, and by 2100, it is expected to be 3°C higher. For the sake of sustainable development around the world in the future, is it essential that the port and harbour sector also proactively proceeds with efforts such as advancing cargo-handling machineries, optimisation of logistics/cargo by utilising AI and IoT, and others.

RESUME


Par exemple, les portiques utilisent généralement des moteurs diesel pour générer l’électricité nécessaire à leur déplacement et au chargement des containers. Ces portiques classiques ont les problèmes suivants : ils consomment une quantité non négligeable d’huile, nécessitent un entretien périodique générant des arrêts d’exploitation, et ont impact important sur l’environnement en émettant du gaz carbonique (CO$_2$), des oxydes d’azote (Nox), etc. En conséquence, en utilisant une source d’énergie externe au portique, on peut réduire les coûts, augmenter le temps de disponibilité, et réduire l’impact environnemental.

Récemment, il a également été demandé d’économiser plus d’énergie et d’améliorer la sécurité des machines de manutention utilisées dans les terminaux à conteneurs. Afin de répondre à ces besoins, des chariots cavaliers hybrides permettant une réduction drastique de la consommation de carburant sont en cours de développement et d’adoption.

Les installations frigorifiques couvertes ont également été conçues pour créer de l’ombre aux conteneurs frigorifiques. L’installation d’un toit permet de réduire la température de leurs surfaces et d’en réduire la consommation électrique.

La température de l’air a augmenté d’1°C depuis la révolution industrielle et d’ici 2100, elle devrait atteindre 3°C. Dans l’intérêt du développement durable dans le monde de demain, il est essentiel que le secteur portuaire poursuive ses efforts proactifs dans le domaine des moyens de manutention avancée, dans l'optimisation de la logistique et du fret en utilisant l’intelligence artificielle, dans l’internet des Objets (IoT), et autres.

**ZUSAMMENFASSUNG**

Um das Pariser Abkommen zu erfüllen, ist es erforderlich, in Japan die Anstrengungen zur Reduzierung von Treibhausgasen etc. voranzutreiben. Aus diesem Grund wird es für die Häfen in unserem Land zusätzlich zur Verbesserung der Sicherheit der Schifffahrt erforderlich sein, fortempschrittene Umwelttechnologien anzuwenden, um einen Wettbewerbsunterschied zu anderen Ländern und Häfen zu schaffen. In diesem Beitrag werden wir die zur Verbesserung der Umwelt in unserem Land unternommenen Anstrengungen untersucht mit dem Fokus auf konkrete Beispiele im Bereich der Hafenlogistik.

Zum Beispiel hat ein RTG (A.d. Ü.: rubber tyred gantry crane / gummibereifter Portalkran), der üblicherweise von einem Dieselmotor betrieben wird und elektrische Energie verwendet, um die Anlage und die geladenen Container zu bewegen, folgenden Probleme: Er verbraucht einen vergleichsweise großen Anteil an Kraftstoff (Erdöl), die Betankung benötigt Zeit, er unterliegt Einschränkungen bei der Betriebszeit bedingt durch regelmäßige Wartung des Motors und er hat eine hohe Umweltbelastung durch den Ausstoß von CO₂, NOx, etc. Durch die Verwendung einer externen Energiequelle anstelle des Aggregats des RTG könnten die Kosten reduziert, die Umschlagszeit optimiert und die Umweltbelastungen vermindert werden.

Im Oktober 2006 haben wir Studien mit Fracht-/Passagier-Schiffen in drei Häfen im Land durchgeführt, die von dem „technological inspection committee for land power supply for ships“ (technologisches Inspektionskomitee für die Landstromversorgung von Schiffen) überwacht wurden. Aufbauend auf den Versuchsergebnissen waren wir in der Lage, die technischen Probleme zu ermitteln und Standardspezifikationen für Landstromversorgungssysteme, Anlagen und Ausrüstungen mit niedrigeren Kosten für verschiedene Schiffstypen vorzubereiten.

Kürzlich gab es auch die Forderung, mehr Energie zu sparen sowie die Sicherheit von Umschlaggeräten, die in Containerterminals eingesetzt werden, zu verbessern. Um einem derartigen Bedarf gerecht zu werden, werden Portalhubwagen mit Hybridantrieb entwickelt und eingesetzt, die eine drastische Kraftstoffeinsparung im Vergleich zu herkömmlichen Geräten ermöglichen.


RESUMEN

Para garantizar el cumplimiento del acuerdo de París, en Japón es necesario continuar avanzando en la reducción de la emisión de gases de efecto invernadero. Por esta razón, en los puertos del país, además de mejorar las condiciones de seguridad en la navegación de los buques, debe profundizarse en la aplicación de tecnologías medioambientalmente avanzadas que permitan aumentar la competitividad en comparación con otros países y puertos. En este artículo se ponen de manifiesto los esfuerzos de mejora medioambiental en el país, poniendo para ello ejemplos específicos en el campo de la logística portuaria.

Por ejemplo, los RTGs habitualmente operan alimentados por motores diésel que generan electricidad que mueve las unidades en su función de carga de contenedores. Sin embargo, las unidades convencionales RTG presentan los siguientes inconvenientes: Utilizan una importante cantidad de carburante, requieren tiempo para su recarga, generan situaciones de inoperatividad durante los periodos dedicados al mantenimiento del motor, y soportan una carga medioambiental derivada de la emisión de CO₂, NOx, etc. En consecuencia, con la utilización de una fuente externa de energía para el generador del RTG se puede generar una reducción de costes, un incremento en el tiempo disponible para operación, así como una reducción de cargas medioambientales.

Se han desarrollado experiencias al efecto en buques de carga y pasaje en tres puertos del país desde octubre de 2006, verificados por el ‘Comité para la inspección técnica del suministro de energía a buques’. A raíz de los resultados obtenidos, se está en disposición de identificar determinados aspectos técnicos y preparar normas de diseño para el suministro eléctrico, incluyendo instalaciones y equipos de bajo coste para distintos tipos de buque.

Recientemente se ha generado también una demanda relativa a la necesidad de ahorrar y mejorar la gestión energética relacionada con la maquinaria que opera en las terminales de contenedores. Para cumplir con estos requerimientos, la utilización straddle carriers híbridos permite una significativa reducción en el uso de combustibles, si se compara con los equipos tradicionales.

Las instalaciones destinadas al ahorro de energía relacionada con la operativa de los contenedores refrigerados, también ha tenido un desarrollo asociado a la creación de zonas de “sombra” generadas por la construcción de tejados, que permiten controlar el incremento de temperatura en estas unidades.

La temperatura se ha incrementado alrededor de 1 grado centigrado desde antes de la revolución industrial, y se espera que para el año 2100 este incremento sea de tres grados. Para permitir un desarrollo sostenible en el planeta es necesario que el sector portuario contribuya a este fin con su esfuerzo y de una manera proactiva, avanzando en campos tales como la operativa de carga/descarga, optimización de las condiciones logísticas utilizando técnicas de inteligencia artificial e Internet de las cosas, etc.
DREDGING AND RECLAMATION CONSIDERING IMPACT ON ENVIRONMENT

by

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Mots-clés: dragage, entretien des chenaux, réduction de l’impact sur l’environnement, prévention contre la pollution, réutilisation des sédiments de dragage

1 INTRODUCTION

In recent years, the reduction of environmental impact associated with construction works has become a strong social requirement; therefore, the selection of construction methods considering only efficiency is no longer possible. Various methods to reduce environmental impact due to dredging and reclamation works have been developed and decreased the burden on environment caused by the construction works. This paper describes the environmental countermeasures developed for marine civil engineering, especially for operations related to dredging and reclamation works, and explains the water quality monitoring methods indispensable for verifying the environmental impact.

2 WATER QUALITY MONITORING IN DREDGING AND RECLAMATION WORKS

Dredging and reclamation works require considerations of various angles from the examination of construction methods and environmental conservation measures to the planning and design stage to avoid significant environmental impacts on the surrounding marine environment. Furthermore, any large-scale dredging and reclamation project requires previous environmental impact assessments, and the project review must incorporate the implementation of conservation countermeasures for all expected environmental effects.

There are several laws concerning the regulation of water pollution in Japan, such as the Basic Environment Act (1993, amended in 2012), the Water Pollution Prevention Act (1970, amended in 2017), the Act on Prevention of Marine Pollution and Maritime Disaster (1970, amended in 2017), etc., in which no clear regulatory values are specified for the water quality changes in marine areas affected by port construction, except for the seawater quality flowing out from spillways. However, in many cases, business operators and contractors voluntarily determine management target values as water quality monitoring standards for individual construction operation to ensure environmental preservation.
Dredging and reclamation works usually consider muddiness (that is, suspended solids or turbidity) as a management target item for water quality changes caused by the construction.

### 2.1. Prediction of Turbidity Diffusion

Prediction of turbidity caused by marine construction requires numerical predictions after specifying the generating factor of the turbidity in the construction. If the predicted turbidity exceeds the management target value, countermeasures to suppress the turbidity must be planned and implemented. The prediction of turbidity diffusion is carried out based on the flowchart (Figure 1) specified in the ‘Guidance on Turbidity Impact Assessment in Port Construction’ issued by the Ports and Harbours Bureau of the Ministry of Land, Infrastructure and Transport and Tourism.

Turbidity diffusion caused by small-scale construction is often predicted using approximate analytic solution assuming that generation of the turbidity occurs as a point source on a two-dimensional plane. The approximate analytic solution is obtained by simplifying the diffusion equation under some conditions. This solution is used to obtain the density distribution of turbidity relatively near the source.

Figure 1: Flowchart diagram for turbidity diffusion prediction

Turbidity diffusion caused by large-scale construction or further assessment required construction regardless of the scale is often predicted by numerical simulation. A numerical simulation is performed by combining a flow model, consisted of continuity and momentum equations, and a water quality model to solve the turbidity diffusion. The turbidity diffusion change resulting from density stratification can be reproduced by incorporating the seawater density change into the flow model and water quality model [Takeda et al., 2010].

Figure 2 is an example of the turbidity diffusion calculation performed to reduce the cost of installing the pollution control membrane that accounts for the major part of the construction cost for maintaining and dredging of waterway and anchorage areas where the amount of dredged material is even small [Kojima et al., 2008]. Figure 2 (a) shows the case where a conventional backhoe dredge and silt curtains around the construction area are used, and (b) the comparable case where an environmentally-conscious grab dredging (SGB construction method) is combined with a frame-type silt curtain at the dredging location. The calculated values of the turbidity distribution after dredging work for 6 hours are shown. The source of the turbidity was assumed as a line source from the seabed to the water surface for conventional backhoe dredging, since a large amount of turbidity is generated in the bucket rising step. On the other hand, the source of turbidity was assumed as a point source on the seabed surface generated during excavation in the SGB construction method using a tightly sealed bucket, since little turbidity is generated in the bucket rising step. The suspended solids (SS) content from backhoe dredging using the silt curtains around the construction area was 4.1 mg/L, whereas the SS from the SGB method without the silt curtains around the construction area yielded the almost equivalent value of 3.7 mg/L at the monitoring point P where the turbidity was worst in the downstream side of the flow. The SGB construction method is more expensive than conventional backhoe dredging but eliminates the cost of installing the silt curtains around the construction area; as a result, SGB can reduce the total cost greatly. In addition, public ship navigation can be maintained during the dredging operation since the silt curtains around the construction area are not necessary to be installed.

Therefore, the SGB construction method can reduce disruption to port users caused by the maintenance-dredging required every several years.
2.2. Water Quality Monitoring for Environmental Surveillance

Environmental surveillance is conducted to confirm the achievement of targeted environmental conservation acted by the environmental conservation countermeasures according to the preliminary plan, to identify unexpected side effects and to consider and implement additional conservation countermeasures based on the surveillance findings. This section describes the environmental surveillance during construction undertaken by the constructor. The constructor carries out the environmental surveillance to facilitate the project so as to minimise the influence on the surrounding environment. The general environmental surveillance procedure is shown in Figure 3.

![Figure 3: Environmental surveillance procedure](image)

**Figure 3: Environmental surveillance procedure**

![Figure 4: Turbidity measurement with water quality meter](image)

**Figure 4: Turbidity measurement with water quality meter**
Turbidity measurements with water quality meters are often used for environmental surveillance in small-scale dredging and reclamation construction as shown in Figure 4. A correlation formula of turbidity and SS is obtained in advance using the bottom sediment and seawater of the target site. The value of SS is converted from the obtained turbidity using the correlation formula. The evaluation points for the turbidity measurement are often set at 2 to 3 locations in the construction area considering the direction of the tidal current. The background value is obtained at a remote point away from the construction area considered to be unaffected by the construction. Then, the converted SS difference between the evaluation point value and the background value is confirmed to be within the control target value. If the control target value is exceeded, previously planned countermeasures are taken.

On the other hand, various water quality data are acquired in large-scale dredging and reclamation construction in preparation for the case that the turbidity exceeds the control target value, as shown in Table 1. Selection of the surveillance points should ensure that accurate assessment of the effects can be achieved, considering the environmental characteristics of the area and the prediction of turbidity diffusion. Figure 5 shows the observation points for environmental surveillance during construction of the Tokyo International Airport Runway D Construction Project [JDREA, 2015].

Table 1: Outline of environmental surveillance during construction

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Survey Items</th>
<th>Survey Method</th>
<th>Survey depth</th>
<th>Survey Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turbidity (SS): the difference between the SS converted value at each evaluation point and the average value of the SS converted value at the background monitoring points should be 10 mg/L or more.</td>
<td>Turbidity SS (conversion) Water temperature Salinity Transparency pH Dissolved oxygen Chlorophyll-a</td>
<td>Water quality meter</td>
<td>Surface layer: 0.5 metre below sea level Middle layer: 5 metres below sea level Bottom layer: 1 metre above seabed</td>
<td>Once a day during construction (Carried out at scheduled time on working day)</td>
</tr>
<tr>
<td>Other monitoring items should not be significantly different from the preliminary survey results.</td>
<td>SS, VSS</td>
<td>Laboratory test (Water sampling)</td>
<td>Same as above</td>
<td>Once a week during construction</td>
</tr>
<tr>
<td>Water colour, red tide, blue tide, bottom trawlers operation, large ship navigation, marine weather, oil film, etc.</td>
<td></td>
<td>On-site (visual) observation</td>
<td>Vicinity of water quality survey points</td>
<td>Once a day during construction (Carried out at scheduled time on working day)</td>
</tr>
</tbody>
</table>

Table 1: Outline of environmental surveillance during construction

Figure 5: Observation points for environmental surveillance during construction
3 DREDGING AND RECLAMATION TECHNOLOGY

In recent years, dredging has often been carried out with a grab dredger since the number of large-scale reclamation projects has decreased in Japan. Dredging with a grab dredger must consider total reduction of the environmental load based on the excavation, transportation and feeding. In addition, soft clayey soil, which is often produced in dredging work, cannot be used for construction material as-is; therefore, technologies for improving dredged soil to reuse as construction material have also been developed. Environmental technology developed for these conditions is described below.

3.1. Dredging Technology

3.1.1. Super Grab Bucket, SGB

Super grab bucket (SGB) is a device designed to suppress turbidity during dredging of contaminated bottom mud or other deposits accumulated on the surface layer of seabed with high mud content as shown in Figure 6. The SGB with high precision processed cutting edge surface and highly durable rubber seal has a higher water-tightness compared to the conventional grab bucket, which suppresses the turbidity generated during dredging (see, Figure 7). In addition, since the SGB is equipped with the function to adjust bucket capacity according to the soil thickness for dredging, high mud content can be dredged without taking in a large amount of water. Combined use with a dedicated thin layer dredging support system can display the planar position, depth of the cutting edge, and open or closed status of the bucket on the water bottom in real time, thus allowing highly accurate dredging work.

![Figure 6: Super Grab Bucket (SGB)](image)

![Figure 7: Leakage comparison (Left is normal grab bucket, right is super grab bucket)](image)
3.1.2. Wide Grab Bucket, WGB

Wide grab bucket (WGB) is a grab bucket that efficiently performs thin layer dredging operations, such as finishing digging. The WGB is wider than the ordinary grab bucket, as shown in Figure 8, but can be mounted on an ordinary large grab dredger. A horizontal digging mechanism and a general construction management system equipped on the grab ship can also be applied.

Using a conventional large grab bucket for finishing digging and thin layer dredging will significantly deteriorate the digging efficiency because the digging ground thickness may be too thin compared to the cutting area. The WGB has a wide bucket opening with a large cutting area, so can efficiently dredge even over a thin layer, and high density dredging with little wastewater is possible. Figure 9 shows the finishing digging pattern compared to that of an ordinary grab bucket.

Since the WGB is a sealed type grab bucket, with higher water-tightness than an ordinary open type grab bucket, turbidity caused by dredging is reduced.

![Figure 8: Wide grab bucket (WGB)](image)

![Figure 9: Comparison of finishing digging patterns (left is wide grab bucket, right is normal grab bucket)](image)

3.2. Transportation Technology of Dredged Materials

Large-scale disposal sites and waste water treatment facilities are required in dredging work using a pump dredger, because the dredged sediment must be transported to the landfill site through a pipeline using a large amount of water. Therefore, large-scale disposal sites and the processing of floating mud become a problem. Consequently, a pneumatic feed method to transport dredged soil with high mud content has been developed. The dredged soil is pumped using air instead of water, so the dredged soil is transported at a higher density than with a pump dredger. In addition, a plug flow mixing method in pipelines was developed to treat soft dredged soil during pipeline transportation by adding binder to the dredged soil during pneumatic feeding. This method utilises turbulent flow, which occurs inside the
pipeline during pneumatic feeding. The soft dredged soil is improved and reused as landfill material, etc. with appropriate strength. Figure 10 shows the outline of the mixing method in the pipeline.

3.3. Reclamation Technology

3.3.1. Double Pipe Tremie Method

The double pipe tremie method with circulating flow is an improvement of the conventional single pipe tremie method for sediment dumping. The two tremie pipes consist of an inner pipe with openings near the water surface and an outer pipe surrounding the inner pipe (see Figure 11). The water level in the inner pipe lowers due to the difference in specific gravity caused by dumping sediment into the inner pipe causing the water in the outer pipe to return to the inner pipe. As a result, the turbid water generated by sediment dumping is circulated between the inner pipe and the outer pipe, so that turbidity can be greatly reduced compared to the single pipe tremie construction method [Kurihara et al., 2003].
3.3.2. PMV (Plant Mixing Vessel) Method

The PMV (Plant Mixing Vessel) method is a construction method mainly to produce treated soil with predetermined strength and fluidity by mixing and stirring binder such as cement into the soft dredged clayey soil, and to use the treated soil as landfill material or backfilling material for bulk-head. The PMV method can carry out all operations from soil production to casting with one dedicated ship. The PMV method can be used for various purposes since an appropriate casting method can be selected according to the construction conditions. In addition, the solidified soil produced by this method has excellent characteristics such lower density than general soil material such as sandy soil, and characteristics can be adjusted to suitable strength and fluidity for intended use, etc. The PMV method has been widely used in Japan, has expanded applications, and has been adopted for large-scale maritime construction overseas. Figure 12 outlines the PMV method.

8 CONCLUSIONS

Environmental management technology for dredging and reclamation was described mainly from the viewpoints of turbidity prevention and reuse of dredged material. Reducing the impact on environment caused by construction works will remain a big problem in the future and we believe that further technological progress is necessary.

We are also working by using ICT in the dredging and reclamation works from early stage; the technology for reducing environmental burden has great potential by combining the latest ICT technology and conventional technology. We will continue our efforts to develop environmental technologies and meet social demands actively.
9 REFERENCES


SUMMARY

This paper describes the environmental management technologies developed for dredging and reclamation mainly from the viewpoints of turbidity prevention and reuse of dredged material and explains the water quality monitoring methods indispensable for verifying the environmental impact.

RESUME

Cet article décrit les technologies de gestion environnementale développées pour le dragage et l’entretien des chenaux, principalement du point de vue de la prévention de la turbidité et de la réutilisation des matériaux de dragage, et présente les méthodes de surveillance de la qualité de l’eau indispensables pour vérifier l’impact des travaux sur l’environnement.

ZUSAMMENFASSUNG

Dieser Artikel beschreibt die Umweltmanagementtechnologien, die für Ausbaggerungs- und Rückgewinnungsmaßnahmen entwickelt wurden, hauptsächlich aus Sichtweise der Trübungsprävention und der Wiederverwendung des ausgebaggerten Materials; er erklärt Methoden zur Überwachung der Wasserqualität, die zur Verifizierung des Umwelteinflusses unverzichtbar sind.

RESUMEN

Este artículo describe las técnicas de gestión medioambiental desarrolladas para las labores de dragado y relleno, fundamentalmente desde el punto de vista de la prevención contra la turbidez y la reutilización de los materiales, mostrando los métodos de monitorización de la calidad de las aguas como elemento indispensable para garantizar un adecuado impacto medioambiental.
In Myanmar, the demand for inbound and outbound port cargo is expected to increase along with economic development. A container terminal construction project was carried out in the Thilawa area located downstream of the Yangon Port. Although the natural conditions in this area are severe in terms of ground and flow conditions, the project was required to be completed in a short period. For the purpose of shortening the construction period, PVD method was carried out for the first time in Myanmar as a soil improvement of clayey soil with a depth of 20-25 m. In addition, jacket and precast-concrete-slab method was adopted for the construction of the jetty (L=400 m) on the steel pipe pile foundation. Accurate pile driving in the Yangon River under the severe river flow conditions was required for installation of the prefabricated jacket structures. By implementing these construction methods, the terminal structures were completed with high quality in a short construction period of 915 days. This paper introduces these construction techniques.

1 INTRODUCTION

Economic growth has been accelerated and cargo logistics have been rapidly increasing since the civilianisation of Myanmar in March 2011, and it is expected that the containers traffic will increase rapidly in the future. Furthermore, it is predicted that the demand of containerised cargo may increase more than the current handling capacity of the country due to the rapid industrialisation around the Yangon urban area. Therefore, the expansion of Yangon Port is urgently required. Figure 1 shows the location of Yangon City and Thilawa Area. The existing Yangon Port is located in the upstream of the Yangon River, which is inconvenient as many vessels cannot enter into the port at low tide because the water depth is shallow. In addition, it is difficult to significantly expand port and harbour facilities at large scale because it is located in the centre of Yangon City. Thilawa port has advantages that it is located in the downstream of the Yangon Main Port, where the port area is deep, and the development of Thilawa special economic zone (SEZ) is strategically planned near the Thilawa port.
Thilawa area is located 16 km downstream of the Yangon Main Port from the Yangon City area. In the container terminal construction, a jetty with a length of 400 m and the design water depth of C.D.L. -10 m was designed to accommodate two 20,000-tonne container ships simultaneously in PLOT No.25 and No.26 along the river, as shown in Figure 2. The project implementation body is the Myanmar Ports Authority. To construct the jetty in a short period, a structure consisting of a jacket and precast concrete slab on the steel pipe pile foundation was considered. Since the jetty is about 67 m away from the revetment, 3 trestles are constructed with the width of 15-20 m and the length of 80-90 m as an access road to the jetty. In addition, a container yard with terminal facilities will be developed on an approximately 18 ha area (700 m in depth and 250 m in width) on the land side. Soft viscous soil is widely dominant in the original ground where the container terminal is to be constructed. In order to minimise the residual settlement caused by vehicle load and container load after commencement of the terminal operation, soil improvement is to be carried out. After completion of soil improvement, 9 buildings including control buildings are to be constructed.

One of the features of this project is that the construction period is only 30 months (from June 2016 to December 2018), which is very short compared to other similar container terminal projects. Therefore, a rapid construction method is required. In addition, the rainy season of Yangon City lasts from June to October during which time precipitation of 3,000 mm can be expected. Yard and pavement work are thus limited to the dry season. On the other hand, maximum flow velocity of this river is 6 knots and the tide level varies from H.W.L. +6.24 m to L. W. L. +0.33 m. The flow velocity is fast, and the tide difference is large. Therefore, we adopted various techniques to complete the construction as planned schedule under these natural conditions which are outlined in this paper.
2 RECLAMATION AND SOIL IMPROVEMENT

2.1 Construction Outline

The typical soil profile is shown in Figure 3. As shown in the figure, clay layers are widely distributed from the river to the onshore part. The work plan view of soil improvement is shown in Figure 4.

On the site, there is a wide distribution of soft and viscous soil layers with a thickness of 20-25 m, and the container terminal is built by reclamation of the sand dredged from the Yangon River. In order to suppress the residual settlement of the terminal yard under the operation load, e.g., container load and vehicle load, after commencement of port operation, surcharge fill was carried out. And in order to shorten the consolidation period by surcharge fill, PVD (Prefabricated Vertical Drain) method was adopted for the first time in Myanmar as the accelerated consolidation method (See Photo 1). PVD is a construction method to accelerate consolidation by installing the drain material with large water permeability to the ground to enhance drainage of pore water. Since sand used for reclamation and sand mat had a small grain size, it was assumed that drain resistance would occur in PVD. Therefore, horizontal drains were installed.

The procedure of the soil improvement is as follows. After laying a geotextile on the original ground of C.D.L. +6.3 m, the sand mat was laid by reclaiming dredged sand up to C.D.L. +7.5 m. Then PVD was placed in a square arrangement of 1.1 m square and horizontal drains were installed. Overview of soil improvement by PVD is shown in Figure 5. As for surcharge fill, the container yard and the utility area were filled up to C.D.L. +11.2 m and C.D.L. +9.3 m, respectively. Each construction area was filled alternately for every 1m of thickness by the dredged sand, pumping from a sand barge through a network of distribution pipes, to prevent the circular slip of the original ground due to rapid loading. When the water level rise occurred inside the surcharge fill in the rainy season, drainage wells and drainage trenches were installed in the surcharge fill area to prevent rise of the water level and to ensure the effective surcharge load. After ensuring the prescribed consolidation of 90 % or more, the surcharge fill was removed to a height of C.D.L. + 8.5 m. Removal of the surcharge fill was carried out when the following requirements were met.

Figure 3: Soil profile of typical cross section
Figure 4: Plan view of surcharge fill
Photo 1: PVD installation
Figure 5: Overview of soil improvement by PVD
(1) The degree of consolidation is 90 % or more with respect to the operation load at the primary consolidation.

(2) The settlement within 20 years after operation of facilities is less than 30 cm, including the secondary consolidation.

After that, it would be shifted to the drainage and pavement work of the container yards and the construction work on the utility yards.

### 2.2 Measurement and Construction Method

The soil improvement of this construction is targeted on a soft viscous soil layer with a layer thickness of 20-25 m. The characteristics of Myanmar clay were investigated by Murakami et al. [1]. The soil particle density $\rho_s$ and the activity of Myanmar clay were generally similar in properties to those of Japanese clay. However, the compression index $C_c$ was half of the Japanese clay at the same liquid limit, and the coefficient of consolidation $C_v$ was less than half of that of the Japanese clay. The uniaxial compressive strength was also about 30 % smaller than that of the Japanese clay and the average of the share strength ratio was 0.225, which was about 2/3 of the Japanese clay. From the above, there is a possibility of overestimating the amount of settlement if the consolidation characteristics are estimated by experience of clay analysis in Japan. Therefore, it is necessary to properly evaluate the soil data collected at the site.

For planning of soil improvement and surcharge fill which can be constructed in the designed construction period, the settlement prediction of consolidation is important. In addition, it is very important to ensure stability of the original ground during surcharge fill. Therefore, prior to construction, additional detailed soil survey of the construction yard was carried out at 10 points, and the soil property and soil layer classification were confirmed. Based on these data, the surcharge fill height and target consolidation period were determined. The results of the consolidation test by the specimen sampled from the borehole at site are shown in Table 1. Depth in the table is the depth from the top of the original ground. The soil profile model based on these data is shown in Figure 6. Since the plasticity index and compressibility were different even in the same clay layer, the clay layer model was divided into 4 layers. The settlement prediction was carried out by finite element analysis program (DACSAR [2]) on the borehole point.

<table>
<thead>
<tr>
<th>Location</th>
<th>Soil Layer (Type)</th>
<th>Depth (m)</th>
<th>$e_0$</th>
<th>$p_f$ (kN/m$^2$)</th>
<th>$C_v$ Value</th>
<th>$C_v$ (cm$^2$/day)</th>
<th>$p$ (kN/m$^2$)</th>
<th>OCR</th>
</tr>
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<td>BH-01</td>
<td>Clay-II-1 (CH)</td>
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<td>1.360</td>
<td>98.1 0.494</td>
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<td>28.85 3.401</td>
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<td>1.979</td>
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Notation:

- $e_0$: initial void ratio, $p_f$: consolidation yield stress, $C_v$: compression index, $C_v$: coefficient of consolidation, $p$: overburden pressure, OCR: over consolidation ratio

Table 1: The results of consolidation test
2.3 Measurement Management

The pore water pressure and consolidation settlement of each layer were measured, at the same site of the ground investigation during surcharge filling period. In addition, the settlement of the ground surface by the settlement plate was measured at 35 points in the yard. For observation of stability during surcharge fill, the underground displacement was measured using the inclinometer at the toe of slope. Moreover, we monitored the ground strength by CPT (Electrical Cone Penetration Test) to confirm the ground stability. Most of the actual measurement values were similar to the predicted values but there were some exceptions. As an example, the measurement results of the settlement amount of No.5 and No.7 are shown in Figure 7. Observation point No.5 in Area1A is the area where the surcharge fill was carried out as the trial area. No. 5 of Area1A was situated between Area4A and Area1B, settlement of this area was thought to be affected by both side surcharge fill. After the surcharge fill in the adjacent area started, the settlement rate decreased. A similar tendency was also observed for No. 7 in Area2A. However, the decrease in the settlement rate was smaller than Area1A. For the above, the following factors were considered, (1) the influence of secondary consolidation, (2) Area1A was loaded both sides, on the other hand Area2A was loaded from one side, so the difference in the restraint of the surcharge fill influenced the settlement rate reduction, (3) the influence of compression index $C_c$, (4) the groundwater level in the surcharge fill was rising, thus the influence of the effective surcharge load was not attained as the predetermined load. Detailed considerations are shown below for each factor respectively.

(1) Results of two-dimensional finite element analysis considering the secondary consolidation in the time-series is consistent with measured settlement (See Figure 8 – blue dashed line).

(2) The surcharge fill was carried out in stages. According to results of analysis, it was assumed that the amount of settlement tends to decrease by adjacent surcharge fill where the horizontal displacement was observed.

(3) According to survey data, compression index $C_c$ varies for each measurement location, thus an initial consolidation analysis was carried out by adopting the average value of $C_c$. On the other hand, in case of No. 5 and No. 7, the results of the analysis were consistent with 0.8$C_c$. The property value of $C_c$ did not change with the settlement, but it was confirmed within the range of statistical variation (See Figure 9).

(4) According to results of analysis which were carried out by actual water level, we found that the soil parameters were generally appropriate.
According to above diagram, it was found that reduction of the settlement rate was due to the water level and no other external factors were observed. Therefore, it was confirmed that the settlement rate was restored by providing the above-mentioned trench and implementing measures to lower groundwater level.

For determining when to remove surcharge fill after the consolidation period, final settlement was predicted by Asaoka Method. The final settlement prediction results of typical observation points are shown in Figure 10.

According to above diagram, it was found that reduction of the settlement rate was due to the water level and no other external factors were observed. Therefore, it was confirmed that the settlement rate was restored by providing the above-mentioned trench and implementing measures to lower groundwater level.

For determining when to remove surcharge fill after the consolidation period, final settlement was predicted by Asaoka Method. The final settlement prediction results of typical observation points are shown in Figure 10. U in the figure is the degree of consolidation. The load condition during construction is the same. However, the amount of settlement and trend differs for each observation point. This is presumed to be due to the spatial non-uniformity of the soil parameters and the difference in the load history originally placed on the ground. The degree of consolidation and the amount of residual settlement were obtained from the
estimated final settlement. Surcharge fill can be removed only after confirmation of the following conditions: (1) the degree of consolidation is 90% or more with respect to the operation load at the primary consolidation, (2) the settlement within 20 years after facilities use is less than 30 cm including the secondary consolidation. In addition, SPT (Standard Penetration Test) was carried out to confirm the increase in the strength of the ground, and the surcharge fill was then removed. From the above, soil improvement in a wide area was implemented in a short period of time.

3 JETTY CONSTRUCTION

3.1 Construction Outline

The construction of the jetty is planned to adopt a method in which the steel piles with three-dimensional truss structures which is called a jacket and built on the temporary building yard, and a pre-cast concrete slab is installed on the jacket (See Figure 11 and Photo 2). In addition, the girders and the floor slabs of three trestles (15-20 m in width, 80-90 m in length) are planned pre-cast method. These methods realise building materials of uniform quality regardless of the external factors including skilled workers and climate. In addition, the construction period can be shortened because it is possible to carry out parallel work of onshore production and pile driving at sea. The velocity of the Yangon River is fast (6 knots), and the tide level differences vary more than 6 m, so these construction methods which require almost no underwater work are useful.

![Figure 11: Outline of jacket structure for jetty](image)

(a) Fabrication of Jacket  
(b) Fabrication of pre-cast concrete slab  

*Photo 2: Superstructures fabrication on land*
3.2 Steel Pile Driving

In the jetty part, 120 steel pipe piles (SPP) of $\phi 1300$ mm were driven. Despite the diameter of the steel pipe pile, inside diameter of the Jacket leg pile is $\phi 1480$, so that gap between them is only 90 mm each side. Thus, highly accurate pile driving was required.

Generally, a pile driving guide is used to obtain high accuracy of the pile position. The setting and removal of a pile driving guide takes a long time, and efficiency of the construction decreases, because distance of the longitudinal direction of the pile is 10 m, and distance of the transversal direction is 16 m. A crane barge (lifting capacity: 400 tonnes) with spud for keeping ship position and pile-keeper which could make a fine adjustment of the pile is used for pile driving. Figure 12 shows a general view of a crane barge with spud and pile-keeper. Furthermore, a barge guidance system using RTK-GPS is employed to control the anchor wires with six sets of winches to perform barge position management and navigation in the fast-flowing river efficiently.

The driving of the steel pile is performed a vibratory hammer for primary driving and a hydraulic hammer for final driving. Because the tide level difference was big, the primary driving with a vibratory hammer leads and is performed continually when the tide level is high. Table 2 shows vibratory hammer and hydraulic hammer specs. The final driving of pile was carried out and quantity of penetration and rebound of per one time of blow were measured when the tide level fell. Photo 3 shows secondary (for final) driving with a hydraulic hammer.

The accuracy of steel pipe piles installation is shown in Figure 13. The average value of pile driving accuracy was 3.8 mm (standard deviation 18.1 mm) on the land side and 0.04 mm (standard deviation 18.0 mm) on the downstream side. More than 90 % of steel pipe piles in both the face line direction and the perpendicular direction were within $\pm 30$ mm of the designed position, and thus high precision pile driving was accomplished.

<table>
<thead>
<tr>
<th>Hull dimensions</th>
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<tbody>
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<td>Gross Tonnage</td>
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</tr>
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<td>Shipbuilding</td>
<td>October 2012</td>
</tr>
<tr>
<td>Crane</td>
<td>Capacity 400t</td>
</tr>
<tr>
<td>Boom length</td>
<td>Max. 78m</td>
</tr>
<tr>
<td>Winch</td>
<td>18t x 6</td>
</tr>
<tr>
<td>Spud</td>
<td>1.2m x 30m (length x 2)</td>
</tr>
<tr>
<td>Pile guide</td>
<td>Max. pile diameter 1,300mm, Max. Angle ±20°</td>
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</table>

Figure 12: General view of a crane barge and pile-keeper

<table>
<thead>
<tr>
<th>Vibratory hammer (ICE 84C)</th>
<th>Hydraulic hammer (IHC S-200)</th>
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</thead>
<tbody>
<tr>
<td>Eccentric moment</td>
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</tr>
<tr>
<td>Blow energy</td>
<td>kNm</td>
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<tr>
<td>Centrifugal force</td>
<td>kN</td>
</tr>
<tr>
<td>Blow Rate</td>
<td>bl/min</td>
</tr>
<tr>
<td>Frequency</td>
<td>vpm</td>
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<tr>
<td>Ram mass</td>
<td>ton</td>
</tr>
<tr>
<td>Amplitude</td>
<td>mm</td>
</tr>
<tr>
<td>Total mass</td>
<td>ton</td>
</tr>
</tbody>
</table>

Table 2: Hammer specs
3.3 Installation of Jacket

Jacket structure is a three-dimensional structure assembling a girder and a brace by a steel material, which is more rigid structure against horizontal forces (See Figure 14). The size of one jacket used at the site is 20 m in the direction parallel to the pier, 40 m in the direction perpendicular to the pier, with a unit weight of 245 t, and there is a total of 20 jackets. The jacket was assembled on the PLOT No.24 yard adjacent to the construction area. A fabricated jacket structure arranged at the yard was loaded on the ‘Till Tank’ and towed by winch for skidding to temporary jetty. After skidding, the jacket structure was lifted by a 500-tonne crane barge. The jacket construction situation is shown in Photo 4. The barge travels on the river by changing anchor and hoisting 6 sets of winches.

In the planning stage, the jacket installation was planned for four days: two days for skidding and preparatory work, one day for lifting the jacket, and one day for shifting a barge and installing the jacket onto SPP. The entire jacket installation was scheduled to be conducted over a three-month period in consideration of daytime work and spring or neap tide. However, there were safety concerns related to the
crane barge lifting a 250-tonne jacket during night time in the severe current condition. In addition, this area is part of an international nautical route. Therefore, the tide level measurement was conducted. It was found that tide lowered one metre per hour after high tide, and a construction plan was made so that lifting and installing the jacket could be completed in one day. This construction plan is shown in Figure 15. With this plan, the entire jacket installation was completed in fifty days. Accordingly, the construction period of jacket work was shortened by forty days.

After connecting the Jacket to the SSP, a crane barge installed the pre-cast concrete slab. In the area beyond the work capacity of a crane barge, the pre-cast concrete slabs were carried and installed by using temporary carrying equipment (See Photo 5).

The jetty construction plan and actual chart is shown in Table 3. By adopting the construction method mentioned above, the construction period was able to be shortened than originally planned.

![Figure 14: Overview of jacket](source)

![Photo 4: Jacket construction situation](source)
This construction project was requested to be completed in a short period of time under severe natural conditions. In order to construct the container terminal on soft ground, the soil improvement period was shortened by applying the PVD method. In addition, the jetty construction adopted the jacket type steel structure and the pre-cast concrete slab, so that a high-quality structure was able to be built in a short period of time. By utilising these technologies, we were able to meet the requirements of the client.
5 ACKNOWLEDGEMENT

This project for construction of the container terminal has been implemented by a joint venture between Toyo Construction Co., Ltd. and JFE Engineering Corporation. We express our appreciation to the people concerned who gave us the opportunity to write this paper.

6 REFERENCES


SUMMARY

In Myanmar, the demand for inbound and outbound port cargo is expected to increase along with economic development. A container terminal construction project was carried out in the Thilawa area located downstream of the Yangon Port. Although the natural conditions in this area are severe in terms of ground and flow conditions, the project was required to be completed in a short period. For the purpose of shortening the construction period, PVD method was carried out for the first time in Myanmar as a soil improvement of clayey soil with a depth of 20-25 m. In addition, jacket and precast-concrete-slab method was adopted for the construction of the jetty \((L = 400 \text{ m})\) on the steel pipe pile foundation. Accurate pile driving in the Yangon River under the severe river flow conditions was required for installation of the prefabricated Jacket structures. By implementing these construction methods, the terminal structures were completed with high quality in a short construction period of 915 days. This paper introduces these construction techniques.

RESUME

Le développement économique de la Birmanie, devrait faire croître les flux de fret portuaire entrants et sortants. Un terminal à conteneurs a été construit dans la région de Thilawa située en aval du port de Yangon. Bien que les conditions hydrauliques et la nature des sols de cette zone soient difficiles, le projet devait être achevé rapidement. Pour réduire le temps nécessaire à sa construction, la méthode DPV (drains préfabriqués verticaux) a été utilisée pour la première fois en Birmanie pour améliorer les sols argileux sur une profondeur de 20 à 25 m.

Des ducs d’albe et dalles en béton préfabriquées ont été utilisées pour la construction de la jetée \((L = 400 \text{ m})\) fondée sur des pieux tubulaires en acier. Une méthode de battage des pieux adaptée aux conditions hydrauliques difficiles du fleuve Yangon à dû être mise en place. En mettant en œuvre ces méthodes de construction, les structures du terminal ont été achevées avec une qualité élevée, dans le délai très court de 915 jours. Cet article présente ces techniques de construction.
ZUSAMMENFASSUNG


RESUMEN

En Myanmar se espera que se produzca un incremento en la demanda de la actividad portuaria ligada al desarrollo económico. Para ello, se ha planteado un proyecto de construcción de una terminal de contenedores en el área de Thilawa, ubicada aguas abajo del puerto de Yangon. Aunque las condiciones naturales de la zona son severas en términos de comportamiento del suelo y corrientes, se requería que el proyecto se completase en un breve período de tiempo. Para conseguir este acortamiento de plazos se utilizó el método DVP por primera vez en Myanmar para la mejora de un terreno arcilloso con una profundidad de unos 20-25 m. Adicionalmente, para la construcción del muelle (L = 400 m) se optó por una solución de losas prefabricadas de hormigón cimentadas sobre pilas metálicas. La precisión en la ejecución de las pilas en el río Yangon, sometido a unas severas condiciones de corrientes, era un elemento clave para la correcta colocación de las piezas prefabricadas. A través de estos procesos se consiguió que las estructuras de la terminal se finalizasen en un periodo de 915 días, con una gran calidad en lo que a su ejecución se refiere. Este artículo describe estas técnicas llevadas a cabo.
INTRODUCTION OF WAVE-DISSIPATING BLOCK TECHNOLOGIES DEVELOPED IN JAPAN AND DISSEMINATION ACTIVITIES ABROAD

by

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Keywords: tsunami, disaster, environment, resilient, long-period waves
Mots-clés: tsunami, catastrophe naturelle, environnement, résilience, houle

1 BACKGROUND AND HISTORY OF DEVELOPMENT OF JAPANESE WAVE-DISSIPATING BLOCK

The world’s first wave-dissipating block ‘TETRAPOD’ was developed in France in 1949. The wave-dissipating and foot protection blocks are now used in various facilities mainly in coastal areas, including ports and fishing ports around the world, and it has spread as technology playing an important role in environment prevention. They are used for breakwaters to ensure the safety of port facilities and the calmness in a port by reducing the energy of waves and for embankments to protect the coast from erosion by waves. It can be said that it is technology that supports safe and affluent civil life behind the scenes. Among them, especially the Japanese wave-dissipating and foot protection blocks are developed independently and evolving.

Japan is an island country surrounded by the sea on all sides. The land area is 377,972 km² (62nd in the world), of which the mountain area occupies 75%. The geographical feature of the coastal area is complex in many places and the coastline extends a total length of approximately 35,000 km which is the 6th longest in the world. In addition, 51% of the total population and 75% of total assets are concentrated in the alluvial plain which is only 10% of the whole land area. Following World War II, the Japanese economy continued to grow by more than 10% annually on average over the 18 years from 1955 to 1973. Energy source changed from coal to petroleum, and on the coast of the Pacific Ocean, industrial complexes stood in a row, spurring concentration of population and assets on coastal areas. In order to support such economic activities, port development was promoted nationwide. At the same time, the development of fishing port facilities were rapidly promoted to secure marine resources that support the people’s diet. Consequently, there are currently 994 ports and 2,866 fishing ports in Japan.

Also, since rivers in Japan are short and have steep bed slopes from mountainous area to plain area compared to Europe and the United States, they run fast. Furthermore, Japan experiences heavy precipitation due to the rainy season and typhoons; its average annual rainfall is about 1,700 mm, nearly twice the world average. In recent years, localised torrential rain assumed to be caused by climate change has also occurred continually. These rainfalls flow downstream all at once by the rapid current, and flooding of rivers and serious damage has frequently occurred in plain areas. Moreover, in coastal areas, high waves and storm surge caused by typhoons which occur annually from summer to autumn cause flooding and inflict serious damage on facilities.
In addition, Japan has historically suffered many other disasters from earthquakes, tsunamis, and volcanic eruption. For this reason, disaster prevention measures in Japan are important policies to protect the economy of the country and the life and property of the people.

Since good large stones were produced in small quantity in Japan, it was difficult to use large stones as the armour material for breakwaters and revetments in the coastal areas. Therefore, the wave-dissipating and foot protection concrete blocks have been developed and used as an indispensable material for the development of port and fishing port facilities and national disaster prevention from the late 1950’s to the present. During this period, various shaped concrete blocks were designed and produced.

Around 1985, in addition to wave-dissipating and disaster prevention functions, blocks began to be used for the creation of landscape and the protection of ecosystems. As a result, about 200 types of blocks are currently used.

In recent years, natural disasters have intensified and thus reinforcement measures against these disasters are urgently required. In ‘Disaster Recovery Programmes from Tsunami Caused by the Great East Japan Earthquake 2011’, the wave-dissipating and foot protection block contributed to the rapid recovery of various facilities and structures. Furthermore, new blocks were developed to reinforce existing facilities against tsunamis in the future.

Japanese wave-dissipating and foot protection blocks which have been developed and evolved over time not only have a wave-dissipating function but also other various functions, and we are confident that they have advantages of function, quality, cost-efficiency, durability, etc. over the blocks used commonly in the world. We hope that Japanese blocks will contribute to port and fishing port development, river and coastal
erosion measures, and the development of social infrastructure such as energy facilities, etc. in foreign countries as well as in Japan.

We hope the Japanese technology applied to wave-dissipating and foot protection blocks introduced in this paper will be an important future reference for you.

2 TECHNOLOGY DEVELOPMENT AND EVOLUTION OF JAPANESE WAVE-DISSIPATING BLOCKS

Currently, 15 private companies are working on the development and dissemination of Japanese wave-dissipating and foot protection blocks. Although each of these companies is making efforts to develop highly stable and more economical blocks having their own unique characteristics, they belong to ‘Nihon Shouha Negatame block Association (Japan wave-dissipating and foot protection block association)’ and cooperate with research on related construction technologies in order to contribute to the improvement of people’s lives by conducting activities to develop and disseminate land conservation and environmental improvement technology. This association recently marked its 51st anniversary since its inception in 1967.

‘Sloping breakwater’ is common worldwide as a structure for securing calmness in ports. However, due to the limited production of good stones used for sloping breakwater, overcrowding of coastal waters usage, large installation water depth of the frontline breakwater, and so on, ‘upright breakwater’ and ‘composite breakwater using caisson’ have been mainly adopted in Japan. The upright breakwater and composite breakwater can reduce the cross section area and the occupied water area of the breakwater compared with the sloping breakwater, and especially in the composite breakwater, the construction cost can be reduced as the water depth increases. Furthermore, in the case where small boats such as fishing boats very often navigate and/or fixed fishing nets are installed outside a breakwater, it is necessary to reduce reflected waves from the breakwater and thus ‘breakwater covered with wave-dissipating blocks’ are often adopted. There are two types of concrete blocks in Japan; one is a structure combined with slender members which is used mainly for wave dissipating and the other is a flat structure which is used for armour of rubble mound. Since the 1960s, new creative concrete blocks of both types which are highly stable and cost-effective have been proposed and adopted. In addition, as breakwaters have been increasingly constructed under more severe wave conditions in offshore areas, more stable concrete blocks were needed which lead to the development of the wave-dissipating block composed of reinforced concrete members. In sea areas with relatively small wave height and short period, the upright wave-absorbing block type breakwater is also used, which is composed of concrete blocks having wave-absorbing space at the ocean side of the block.

Also, various protective facilities such as sea embankment, gentle-slope revetment, wave-absorbing breakwater, detached breakwater, jetty, and artificial reef have been developed to protect the people living in densely populated coastal areas, the numerous cumulated social capital, etc. from tsunamis and storm surges and to protect the coastline from erosion. Sea embankment and gentle-slope revetment are installed for the purpose of reducing overtopping discharge to coastal land areas and enabling safe access to the coast. And detached breakwater and jetty are installed to encourage natural sediment to regenerate the eroded coast. Artificial reef is a coastal structure that satisfies both erosion measures and landscape preservation. It is installed in submerged sea zone and has the effect of attenuating the wave energy reaching the coast by forcibly breaking waves on the reefs. For these structures, both slender member type and flat type blocks are applied and produce good effects.

In the Great East Japan Earthquake which occurred in 2011, huge tsunamis caused enormous damage to the Pacific Coast of Tohoku and Kanto regions. The Ministry of Land, Infrastructure, Transport and Tourism released ‘Tsunami-Resistant Design Guideline for Breakwaters’ in order to restore breakwaters damaged by the tsunami and to design breakwaters against future tsunamis. In the case of ‘design tsunami’, the guideline aims ‘disaster prevention’, which means full protection of human life and properties with a breakwater, while for tsunamis of a scale exceeding the ‘design tsunami’, ‘disaster reduction’, which means minimising damages as much as possible and protecting human life is the goal. A breakwater structure should not be damage when a ‘design tsunami occurs while the structure should maintain disaster reduction effect as long as possible and be resilient’ (it should not collapse even if it changes its shape) in the case of a tsunami which exceeds the ‘design tsunami. Additional measures are decided in consideration of the importance of property to be protected, cost-benefit analysis, etc. In order to make a breakwater resilient, several technologies were proposed. Previously, it was common to fortify the harbor side of a
breakwater with a mound of rubble stones which is covered with armour blocks to protect against tsunami overflow. New technology has been developed, however, in which cellular blocks filled with stones are installed as a counterweight at the harbour side of a breakwater.

In the Great East Japan Earthquake, giant tsunami overtopped the crown of the embankment, scoured its back slope and destroyed the whole structure. Learning from this, flat type blocks were placed as the armour material to avoid the same damage and to reinforce the crown and back slope toe.

Photo 4: Embankment damaged by tsunami
(Provided by Water and Disaster Management Bureau, MLIT)

Photo 5: Example of construction of a recovered embankment
(Left photo: Seaward side, Right photo: Landward side)

In recent years, in addition to the wave-dissipating function, technologies related to block shapes such as providing grooves to create fish and shellfish habitat and for use as a growth base of algae, and concrete mixed amino acid to promote the growth of algae, etc. have been developed, adopted and are producing good results.

Photo 6: Algae growing on concrete containing amino acid
Thus, Japanese wave-dissipating and foot protection blocks continue to evolve and be improved. In the next chapter, we will introduce recent developments and concrete examples of these wave-dissipating and foot protection blocks being adopted in overseas projects.

3 TECHNOLOGY AND OVERSEAS DEVELOPMENT BY MEMBER COMPANIES OF THE ASSOCIATION

3.1 State-of-the-Art Technology and Overseas Development of Wave-Dissipating Blocks of FUDO TETRA CORPORATION

Fudo Tetra Corporation is undertaking research and development, and field applications, including mold leasing, of wave-dissipating and foot protection blocks. We are also engaged in providing various engineering and design services for waterfront areas, and in technology development to protect landscapes and ecosystems. We are confident that the technologies we have been developing for wave-dissipating blocks for more than fifty years will contribute to economic development and disaster mitigation in many countries.

This paper introduces a few of our latest technologies and recent overseas business activities in providing our wave-dissipating blocks.

3.1.1 State-of-the-Art Technologies Related to Wave-Dissipating Blocks

(1) Tsunami Protection Technologies for Breakwaters

To strengthen a breakwater’s ability to withstand tsunami, an effective method is to raise a mound inside the port with levee-widening stones. Since these widening stones are exposed directly to overtopping tsunami driving into them, it is essential to adequately protect them from being scattered. We have therefore proposed a technology to make breakwaters much firmer and tougher by protecting the mound with armor blocks. This has proven to be successful in many cases throughout Japan. Such armour blocks are Permex. They have achieved superior stability through substantial reduction of uplift pressure by means of large openings. (Figure 1)

The required mass of the blocks to be used can be determined by using our unique calculation method developed on the basis of in-depth studies of phenomena through experiments using hydraulic models and numerical analysis.
(2) Submerged Mound against Long-Period Waves

Many ports report that long-period waves inside the港 have made cargo-handling operations inefficient and cause accidental contact of hulls with quay walls, resulting in breakage of mooring ropes, etc.

Using submerged mounds to cope with long-period waves (Figure 2) is a method adopted to ensure a high wave dissipation effect by lowering the crest height of the structure to the still-water level to reduce reflected waves on the slope, and also by damping wave energy with wave-dissipating blocks arranged wide area on the crest. Unlike the conventional emerged mound, the section can be downsized, and can be reduced by about 20%. Our proposed technology has been employed at Kashima Port, is being developed as an international logistics terminal.

3.1.2 Development of Block Business in Korea (Tetraneo, Dolos II)

We are expanding our block business in Korea. In 2012, the company concluded a license agreement with a Korean company that allows block mold fabrication, application, and lease of our three new block types (Tetraneo (Figure 3), Dolos II (Figure 4), and Permex).

We provide overall technical support including mold design, management, and implementation to the Korean enterprise. This contributes to the utilization of the blocks in various parts of Korea. Figure 5 shows the locations where the blocks have been used.
3.1.3 New Challenges in Africa

(1) Projects in Africa 1) Lome Fishing Port in Republic of Togo (Tetraneo)

The Lome Fishing Port Development Project in the Republic of Togo (Japanese Grant Aid Project) is to build Lome, a new fishing port, the only fishing port in the country. Figure 6 shows the location and provides an image of the completed port.

The wave-dissipating blocks used are Tetraneo blocks, which are appropriate to local conditions. Tetraneo offers superior stability, economic efficiency and structural strength.

Developed on the basis of Tetrapod technology and with a solid record of success, Tetraneo is a block that provides high reliability and high stability, with a Kd value of 11 through a unique shape design with projections at the end of the block legs. In addition to the superior structural strength achieved by increasing the sectional area of the leg bases where stress concentrates, downsizing of blocks by stability improvement and the high porosity of 60% enabled a reduction of construction costs.

Many local workers had never been involved in constructing wave-dissipating blocks. In response to a request from the contractor, we provided guidance by our engineers concerning fabrication and installation of the blocks. (Photo 7).

(2) Projects in Africa 2) Toamasina Port in Republic of Madagascar (Dolos)

For Toamasina Port, the largest commercial port in the Republic of Madagascar, developing the capability to handle increasing numbers of containerised cargoes and to cope with the growing size of bulk freighters was an urgent issue. In this context, the Toamasina Port Expansion Project was started in 2018 as a Yen Loan Project. Figure 7 shows the location of Toamasina Port.
Since Toamasina Port is located in an area subject to extremely severe conditions, with a design wave height exceeding 10 meters, reinforced Dolos blocks (Figure 8) were utilised as wave-dissipating blocks. This product is highly evaluated both in and outside Japan because of its high reliability, which was achieved due to the company’s accumulation of experience in the severe high wave range. This product has been used with great success in Japan, where more than 110,000 blocks have been used, mainly for ports and fishing facilities.

The Kd value of Dolos is as high as 20 t, 30 t and 50 t types may be appropriate for Toamasina Port because of its superior stability. For development of this port where the waves are normally high and offshore installation of blocks is difficult, minimisation of block weight is essential to meet required performance expectations.

Compared with Tetrapod, which has a radial shape, Dolos has an anchor-type shape, which tends to afford higher stability because of the interlocking effect. Concerning the structural strength, Dolos tends to have higher stress occurring within the members. It was developed in 1963 as a non-reinforced block. After introduction in Japan, not only desk analysis, but also actual destruction tests were conducted. Tracking studies were conducted after they were introduced on-site. Now Dolos has about 93 kg per m$^3$ for reinforcement (of 50 tonne-type) and affords high structural strength. These blocks have a proven record of success in the high wave range. Figure 9 shows the transitions that have occurred in Dolos reinforcement.

Adopting a long-term viewpoint, the company is moving ahead with technology development. One project is to promote attaching coral onto blocks. This is being done with the aim of ensuring that living organisms can coexist with port structures. Repeated field studies of the use of Dolos has proved that working the block surface into a concave-convex condition using concrete placement outlets promotes the attaching of coral.

We are confident that Dolos blocks of Japanese specification will contribute to the Toamasina Expansion Project due to the high stability and structural strength they provide. We have developed independently due to the experience we have gained from successful projects under severe wave conditions. We are also sure that the added functions being developed to facilitate environmental protection will prove beneficial.

3.2 Overseas Development of SANSHOSUIKO CO., LTD

Since its foundation in 1972, Sanshosuiko has been developing and disseminating technologies in Japan, centering on ‘SEALOCK’, a wave-dissipating block and ‘WAROCK’, an upright wave-dissipating block.

As an overseas project, ‘WAROCK’, was first adopted in 2004 at the port quay-wall facing Bosphorus Strait in Republic of Turkey where Western and Eastern civilizations meet. Then, we started to provide technical cooperation on design and construction works relating to the wave-dissipating blocks used in breakwaters and coast protection in South Korea in 2005.
At that time in South Korea, ports and fishing ports were actively developed and growing rapidly, and Tetrapod of 30 tonnes or less was widely used as a wave-dissipating block. However, as the vessels grew in size, breakwaters had to be constructed in deep sea areas and large-sized wave-dissipating blocks were required. Nevertheless, there was almost no actual experience in fabrication and installation of the large-sized wave-dissipating blocks in South Korea. In contrast, the large wave-dissipating blocks of 80 tonnes or more were used at many deepwater breakwaters in Japan.

A Korean company wished to obtain this technology and requested us to provide technical cooperation. In response to their request, we have been assisting with block stability model experiments, cross section design, strength calculation of the block and the mold, a review of the casting and construction methods as well as supplying molds from Japan.

Our wave-dissipating block technology which was developed in Japan has been applied in Turkey and South Korea, and we believe that it will surely contribute to the development of ports in the member countries of PIANC.

We are looking forward to hearing from everyone participating in PIANC AGA KOBE.
3.3 Efforts Toward Overseas Business Development and Wave-Dissipating Block Technology of NIKKEN KOGAKU CO., LTD.

Since our foundation in 1964, we have been working on the development and dissemination of new wave-dissipating block technologies in Japan aiming at protecting national land from various natural disasters such as typhoons, tsunamis, floods and coastal erosion, and the conservation of a rich natural environment. In 2010, we started an overseas business in South Korea and Vietnam and are developing wave-dissipating block business for Southeast Asia, South Asia and Africa as well. In this paper, we will introduce our efforts for overseas business development, our technologies and activities in PIANC.

3.3.1 Toward Business Development Overseas

When developing overseas business, we emphasize partnerships with universities and research institutions in various countries. Through joint research with partners such as Thuy Loi (Water Resources) University in Vietnam, Seoul National University in Korea, Agency for Assessment and Application of Technology (BPPT) in Indonesia, we conducted both scholarly and technical verification and evaluation of our wave-dissipating blocks under local marine meteorological conditions and construction conditions and clarified its advantages. Moreover, by presenting these research results to international conferences such as PIANC, ISOPE, ICCE, etc., the merits of our technology have been widely recognised. Together with our partners, we are making efforts for our wave-dissipating blocks to be adopted as technical standards of each country.
3.3.2 Wave-Dissipating Block ‘RAKUNA-IV’

RAKUNA-IV (hereinafter referred to as RAKUNA) is a wave-dissipating block with four hollows on its surface developed in collaboration with Kyoto University Disaster Prevention Research Institute in 2007. RAKUNA has been used in Japan as the wave-dissipating block for breakwaters at ports and fishing ports and for detached breakwaters and revetments for measures against coastal erosion and has accumulated achievements of more than 1 million tonnes in total concrete volume at the total of 74 sites (as of October 2018).

When we launched a RAKUNA business in Vietnam, we made joint model experiments with Thuy Loi (Water Resources) University in Vietnam to verify and evaluate the stability and wave-dissipating performance of RAKUNA under local conditions. The model experiments were conducted for the rubble mound breakwater which was often adopted outside Japan. Through this experiment, it became clear that RAKUNA has high stability in the rubble mound breakwater, despite its excellent economic efficiency due to high porosity. This research results were reported at various conferences and seminars in Vietnam, and RAKUNA was adopted as one of the usable concrete blocks in the Vietnamese Technical Standards.

RAKUNA was first adopted in Vietnam in the Nghi Son project completed in December 2015. The breakwater was constructed for the port facility of Nghi Son Refinery and Petrochemical Complex (NSRP) which is the second refinery in Vietnam, and approximately 24,000 RAKUNA (8-ton, 12-ton) blocks were used. In the original master plan, the single layer system block was proposed. However, the construction company changed to RAKUNA because of the following two advantages: ‘initial cost reduction’ and ‘life-cycle cost reduction by resilient structure’. In determining the cross-sectional shape of the breakwater, we conducted the wave flume (2-D) experiment and the wave basin (3-D) experiment in collaboration with Thuy Loi (Water Resources) University in Vietnam. At the construction stage, we provided technical support such as supplying the steel molds made in Vietnam and supervising the fabrication and installation of the blocks. Consequently, in the final inspection of the marine facilities in NSRP, Deputy Minister of Construction in Vietnam shared the following words of praise: “Quality of design and construction of NSRP was the best in Vietnam, and especially the high quality RAKUNA should be expanded in Vietnam”.

In addition, approximately 4,600 RAKUNA (16 tonnes, 32 tonnes) blocks were also adopted in the Chan May Port Breakwater Construction Project ordered by Hue Province in Vietnam. Also, in the Patimban Port Development Project in Indonesia, which will be developed under a Japanese ODA Loan, it has been decided to adopt approximately 20,000 RAKUNA (2 tonnes) blocks at the breakwater based on the verification and evaluation of stability and wave-dissipating performance by Agency for Assessment and Application of Technology (BPPT) in Indonesia.
3.3.3 High Stability Block for Severe Wave Condition, ‘SANREN GRASP’

‘SANREN GRASP’ (hereinafter referred to as GRASP) was developed in collaboration with Disaster Prevention Research Institute, Kyoto University in 2009 and it is a wave-dissipating reinforced concrete block with three legs at each end of the shaft part. GRASP exerts high stability (Kd = 20.6) by the firm interlocking of blocks. It is used particularly in places with severe wave conditions such as Sado Island in Niigata Prefecture where design wave height exceeds 9 metres. Also, since the weight of the block can be reduced, and it is possible to install it by using smaller construction machines, there is an advantage for a country which has difficulty in procuring large machines. GRASP can realise the most economical cross section among the wave-dissipating reinforced concrete blocks because it has a very high porosity (63.5%) and allows the number of blocks used to be drastically reduced. The blocks can be fabricated safely and temporary placement is carried out in the manner shown in Photo 21, so the yard area can be remarkably reduced. There is no fear of corrosion because the hanging steel bars are not attached to GRASP. Moreover, it is easy to install randomly, which reduces the working hours of crane operators and divers as well as the risk of accidents which can be major concerns at deep-sea sites.

We would like to increase the chance to use wave-dissipating reinforced concrete block GRASP which is superior in economic efficiency and workability at overseas sites with severe wave conditions.
3.3.4 Activities in PIANC

Nikken Kogaku joined PIANC as a corporate member in 2012 and has closely followed PIANC activities. Our young engineers are actively taking part in the PIANC YP-Com (Young Professionals Commission), and in 2013, we received the PIANC De Paepe-Willems Award, the best paper award for young engineers, for the first time in Asia. The theme of this paper is ‘SUBPLEO-FRAME (SPF)’, the caisson type breakwater reinforcement method against tsunamis. SPF is a simple structure in which concrete cellular blocks are installed in the harbour side of a breakwater and stones are filled into the center hole. The sliding resistance of the caisson breakwater increased by interlocking between filling stones restrained by SPF and mound stones, which makes it possible to build a resilient structure. In reconstruction work of the Port of Hachinohe, which was seriously damaged by the Great East Japan Earthquake Tsunami in 2011, SPF was adopted to make the breakwater resilient.

In 2018, the Port of Wajima Breakwater Demonstration Project using a new technology ‘Environmentally Active Concrete’ (hereinafter referred to as EAC) which is concrete mixed with amino acid was awarded the PIANC Working with Nature Certificate of Recognition. The amino acid that elutes from the surface of EAC into the water has the effect of promoting the growth of microalgae and seaweed adhering to the surface by 5 to 10 times more compared to normal concrete. The panels made of EAC have been installed in over 100 sites in ports, fishing ports, coasts and rivers in Japan so far. At the 34th PIANC World Congress in Panama in 2018, we presented the paper on the algae growth promotion effect and the creation effect of various organism habitats confirmed in the Port of Wajima Demonstration Project.
3.3.5 Towards Future Efforts and Achievement of SDGs

We will continue to strengthen the partnerships with engineers through collaborative research with universities and research institutes in foreign countries and disseminate resilient disaster prevention technologies and environmental technologies full of originality that incorporate the experience and knowledge unique to our disaster-prone country, Japan. We are convinced that the accumulation of these steady efforts will contribute to the achievement of ‘Goal 9: Build resilient infrastructure, promote inclusive and sustainable industrialisation and foster innovation’ and ‘Goal 14: Conserve and sustainably use the oceans, seas and marine resources for sustainable development’, that are listed in the Sustainable Development Goals (SDGs) of the United Nations.

4 CONCLUSION

In this paper, we introduced technology related to wave-dissipating and foot protection blocks that has been developed in Japan for over 50 years and how such blocks are increasingly being adopted in projects in various foreign countries due to overseas business development efforts of three companies. This technology will be in demand not only for projects related to the development of ports and transportation infrastructure, disaster prevention infrastructure, energy infrastructure, etc. in developing countries but in developed countries as well. Our technology is also indispensable for the realisation of sustainable development goals (SDGs).

We hope that Japanese wave-dissipating and foot protection blocks will contribute to solving the problems and realizing SDGs of the countries in the world through these projects and we would like to continue active dissemination in the future.

Finally, we would like to thank PIANC, PIANC Japan and Ports and Harbours Bureau, Ministry of Land, Infrastructure and Transport and Tourism for giving us this opportunity to discuss our technology.

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5  REFERENCES

PIANC


ISOPE

SUMMARY

The world’s first wave-dissipating block ‘TETRAPOD’ was developed in 1949 and are still in use some 70 years later. They now play an important role in disaster prevention at various facilities (mainly in coastal areas) and continue to support safe and affluent civil life behind the scenes. Above all, the Japanese wave-dissipating and foot protection blocks are developed independently and evolving.

The coastline of Japan extends a total length of approximately 35,000 km. Along with the economic growth after World War II, coastal development including the improvement of port and fishing port facilities have been rapidly implemented throughout Japan, and now 3,860 ports are in operation. In addition, disaster prevention measures for a nation like Japan which is prone to typhoons, storm surge, heavy rain as well as earthquakes and accompanying tsunamis are of vital importance.

Against this background, the development of Japan's own wave-dissipating and foot protection blocks have progressed over the past 60 years and they have been used for breakwaters to ensure the calmness of water facilities and the safety of ports and fishing port facilities, and embankments to protect the coast from erosion by waves. Recently, in addition to wave-dissipating function and erosion protection, blocks with more diverse applications such as the creation of landscapes and conservation and reproduction of ecosystems are being designed. So far about 200 kinds of blocks have been used in Japan.

Moreover, they have various advantages compared to the wave-dissipating and foot protection blocks used elsewhere in the world and can contribute to the infrastructure improvement of many countries. This paper describes the development history of Japanese wave-dissipating and foot protection blocks and examples of adoption in overseas projects.
RESUME

Le premier bloc du monde pour la dissipation de l’énergie de la houle, TETRAPOD, a été mis au point en 1949 et est encore utilisé quelque 70 ans plus tard. Il joue désormais un rôle important dans la prévention des risques d’installations diverses (principalement dans les zones côtières) et continue discrètement son rôle de protection des populations. Dans le même temps, les blocs japonais ont été développés de façon indépendante et sont toujours en évolution.

Le littoral japonais s’étend sur environ 35 000 km. Parallèlement à la croissance économique qui a suivi la Seconde Guerre mondiale, le développement côtier, dont l’amélioration des installations portuaires et des ports de pêche, a rapidement concerné tout le Japon et 3 860 ports sont maintenant opérationnels. En outre, les mesures de protection contre les catastrophes dans un pays comme le Japon, sujet aux typhons, aux tempêtes, aux fortes pluies, aux tremblements de terre et aux tsunamis qui les accompagnent revêtent une importance capitale. Dans ce contexte, les blocs de carapace et de protection des pieds de digues du Japon ont progressé au cours des 60 dernières années. Ils ont été utilisés sur les digues destinées à réduire l’agitation autour des installations nautiques ou assurer la sécurité des installations portuaires industrielles et des ports de pêche, ainsi que sur les ouvrages de protection du littoral vis-à-vis de l’érosion côtière. Récemment, en plus de la fonction de dissipation de l’énergie de la houle et de la protection contre l’érosion, des blocs sont utilisés dans des contextes élargis, tels que la création d’aménagements paysagers, la conservation ou la reproduction d’écosystèmes. À ce jour, environ 200 types de blocs ont été ou sont utilisés au Japon.


ZUSAMMENFASSUNG


Darüber hinaus haben sie verschiedene Vorteile, verglichen mit den Blöcken, die woanders in der Welt für die Wellendissipation und den Uferschutz eingesetzt werden, und können zur Verbesserung von Infrastrukturanlagen in vielen Ländern beitragen. Dieser Beitrag beschreibt die historische Entwicklung der japanischen Wellen-Dissipations- und Uferschutz-Blöcke und gibt Beispiele für eine Übernahme in ausländischen Projekten.
RESUMEN

El primer bloque disipador del oleaje, el Tetrápodo, se desarrolló en 1949 y se encuentra todavía en uso 70 años después. A día de hoy, este tipo de piezas juegan un papel importante para la prevención contra desastres y para el desarrollo de instalaciones (fundamentalmente en zonas costeras) y continúan respaldando el desarrollo de comunidades y actividades en las zonas protegidas. La técnica de los bloques destinados a disipación de energía y protección frente a socavación continúa evolucionando en Japón.

La línea de costa en Japón se extiende sobre una longitud de aproximadamente 35.000 km. Consecuentemente con el desarrollo económico experimentado tras la Segunda Guerra Mundial, el desarrollo costero, que incluye la generación de puertos e instalaciones pesqueras, tuvo un rápido crecimiento a lo largo de todo el país, de tal modo que actualmente existen en uso 3.860 instalaciones portuarias. Adicionalmente, las medidas de protección frente a desastres costeros en un país como Japón, sometido a tifones, temporales, tormentas y terremotos, con los consiguientes tsunamis asociados, resultan de vital importancia.

Frente a esta situación, en Japón en los últimos 60 años se ha desarrollado el diseño de bloques que actúen frente al oleaje y contra la erosión, habiendo sido utilizados para la construcción de diques de protección en instalaciones portuarias y pesqueras, así como para la defensa de costa frente a la acción del oleaje. Recientemente, además de para los usos anteriormente mencionados, se han diseñado piezas con otras aplicaciones tales como la generación de superficies o para la conservación y reproducción de ecosistemas. De este modo, alrededor de 200 tipos de piezas han sido utilizadas en Japón.

Además, presentan diversas ventajas en comparación con otros tipos de piezas que se utilizan en otros países, por lo que pueden ser utilizadas en desarrollos que se planteen fuera de Japón. Este artículo describe el desarrollo de este tipo de piezas en Japón y muestra ejemplos de aplicación llevados a cabo fuera del país.
DESIGN BASIS OF FENDERS FOR BERTHING AND MOORING FACILITIES IN PORTS AND HARBOURS

1.1 Basis of Fender Design for Berthing Ship

Rubber fender is designed to absorb a ship’s berthing energy [Ports and Harbours Association of Japan, hereafter PHAJ, 2018]. A ship’s berthing energy is calculated by equation (1) considering those factors as mass of ship, berthing velocity, virtual mass factor, eccentricity factor, softness factor and berth configuration factor.

\[ E_f = \frac{1}{2} M_s V_b^2 C_m C_e C_s C_c \]  

Where, \( E_f \): ship’s berthing energy (kJ), \( M_s \): mass of ship (t), \( V_b \): berthing velocity (m/s), \( C_m \): virtual mass factor, \( C_e \): eccentricity factor, \( C_s \): softness factor, \( C_c \): berth configuration factor. Ship’s berthing energy is proportional to mass of ship and the square of ship’s berthing velocity. Particularly, the ship’s berthing velocity greatly influences the selection of performance of rubber fender. Based on past records, design-berthing velocity of a large cargo ship is about 0.1 to 0.15 m/s when gently berthing lining parallel to the berth with the assistance of tugboats.

Part of ship’s berthing energy would be absorbed by deformation of ship hull and mooring facilities, but generally, energy absorption due to deformation of ship hull is not considered because of smallness. As for rigid mooring facilities such as gravity type and sheet pile type structures which are structurally undeformable, energy absorption by deformation of those facilities is not considered as energy absorption.
On the other hand, energy absorption can be considered for flexible mooring facilities such as pier type structures which are structurally deformable. For example, mooring facilities of a single pile structure composed of high-tensile steel, energy absorption due to deformation of a pile is considered in fender design.

For rigid mooring facilities, energy absorption of fender is determined by the performance-checking equation by equation (2).

\[ E = \phi E_{cat} \geq E_f \]  

(2)

Where, \( E \): energy absorption of fender (kJ), \( \phi \): influence factor of fender performance, \( E_{cat} \): normal energy absorption of fender (kJ), \( E_f \): ship’s berthing energy (kJ). As for deformable flexible mooring facilities such as pier type structures, it is necessary to pay attention to the reaction force, because fender reaction force would be the design horizontal force for structures when seismic horizontal force is relatively small.

1.2 Fender Design in Consideration of Motions of Moored Ship

Basically, a fender is designed to absorb a ship’s berthing energy. However, in the case of mooring facilities which are located at a port facing the open sea, it is necessary to consider impact force by ship motions induced by direct incident waves. In this case, it is necessary for fender design to consider the impact force obtained by a numerical simulation of moored ship motions [Ueda, 1983]. With a numerical simulation of a moored ship, time series of moored ship motions is obtained by calculating equations of motions in time domain considering such factors as random wave and wind forces, current forces and nonlinear load-deflection characteristics of mooring system consisting of fenders and mooring ropes.

According to some results of the numerical simulation of moored ships [Ueda, 1992], fender deflections by ship motions would be larger than those by berthing ships in the cases when moored ships are subjected to long period waves like a swell, when ships are in beam seas and when the ratio of the energy absorption and allowable fender deflection is large. In such a case, it is recommended to choose a fender with relatively larger allowable deflection among fenders of same energy absorption.

In addition, it is also important for accurate evaluation of the cargo handling rates of a moored ship which is subjected to wind wave, swell and long period wave in order to examine suitable mooring system using optimal fenders and ropes [Coastal Development Institute of Technology, hereafter CDIT, 2004]. If the influence of the motions of a moored ship is heavy in cargo handling, it may be possible to improve the cargo handling rate by selecting suitable fenders and mooring ropes.

Fig. 1 shows an example of the performance verification procedure of rubber fender [PHAJ, 2018]. As shown in the figure, the performance verification of rubber fenders is separately carried out for berthing ships and for moored ships.
1.3 Introduction of Reliability Design Method in Fender Design

In Japan, the Partial Factor Design Method based on the Load and Resistance Factor Design Method has been basically introduced in the design of port and harbor facilities, while it has not been yet applied in fender design. However, many researches on the reliability design method of rubber fenders have been conducted in Japan. For example, Ueda et al. examined how to obtain the partial factor for ship’s berthing energy by estimating the probability distribution of each parameter constituting the performance-checking equation of fender and by calculating failure probability of fender by Monte Carlo simulation [Ueda, 2002]. Nagao et al. proposed the partial factors for each parameter of ship’s berthing energy formula by applying the First-Order Reliability theory (FORM: First-Order Reliability Method) and by using the probability distribution of these parameters [Nagao, 2003]. Moreover, Yoneyama et al. studied the safety evaluation of fender by reliability analysis considering temperature factor and velocity factor and calculated the partial factors in the Level 1 Reliability Design Method [Yoneyama, 2004]. Yoneyama et al. also applied a reliability analysis based on the First-Order Reliability Method to fender design and proposed the partial factors of the performance-checking equation of fender corresponding to various types of ships [Yoneyama, 2006]. In the future, it is expected that research achievements such as those above will be utilised to establish the reliability design method of rubber fenders.

2 HISTORY OF FENDER DEVELOPMENT ON TYPE AND SIZE

2.1 Upsizing of ships and associated fender development

Fender development has been greatly influenced by development of ships and ports and harbours. Figure 2 shows the history of the upsizing of ships and associated development steps of rubber fenders.

In the rapid economic growth era of the 1970s in Japan, the size of crude oil carriers increased to more than 500,000 DWT, so as to reduce the shipping charge for crude oil, which necessitated the development of upsized and hi-performance rubber fenders. However, the size of crude oil carriers eventually reverted to 300,000 DWT class. On the other hand, upsizing of container ships is an ongoing trend. Compact rubber
fenders with high-efficient energy absorption were developed. Next generation container ships will require the development of higher quality and more durable rubber fenders.

![Figure 2: Change of ship size and rubber fender generations](image)

### 2.2 Fender Development Stages

Figure 3 shows the rubber fender development at each stage by comparing load-deflection characteristics of the maximum size rubber fender at each development stage.

1) **Used Tire, Timber & etc.: Before rubber fender was development (before 1950)**
   Used tires, timbers and other materials were used on the quay wall for ship’s berthing before the development of rubber fenders. In spite of small energy absorption of those materials, they were adequate to absorb the berthing energy of small ships.

2) **I. Cylindrical fender: First stage (from 1950)**
   The first popularised rubber fender was a hollow cylinder rubber fender which was installed by hanging at quay wall. Because of the excellence of its cushioning properties, it became popular and took place of timber. In spite of its relatively small energy absorption efficiency, it is still used today for small ships such as fishing boats and working ships.

3) **II. Buckling fender – Direct contact: Second stage (from 1955)**
   V type fender of excellent energy absorption with buckling deformation was developed, thereby fenders became to have the performance of both of large energy absorption and small reaction force.

4) **III. Buckling fender – Panel contact: Third stage (from 1960)**
   Due to the enlargement of ship size, large-sized fenders were required. Hull strength of large sized ships such as large sized crude oil carriers and bulk cargo ships is relatively small, therefore fenders with panel contact were developed as to reduce hull contact pressures of fenders. The maximum size of buckling fender with panel contact is 3 m (3,000 H) in height. It is necessary to support heavy weight of fender panel by chains to prevent fenders from drooping.

5) **IV. High compression fender – Panel contact: Fourth stage (from 1990)**
   High-performance new medium-size rubber fenders were developed in response to the growth in the number of container ships. The maximum strain of new medium-size rubber fenders is about 65 to 72.5 % of their height because of buckling and folding deformation, while the maximum strain of conventional fenders is about 45 to 55 %.
As for rubber fenders, it is preferable to have higher energy absorption with low reaction force. PIANC WG 33 [PIANC, 2002] describes that, the factor $R/E$ which is reaction force divided by energy absorption, is called Fender Factor and is used as one of the indicators of fender performance.

### 3 PERFORMANCE OF FENDER

#### 3.1 Compression Performance

Compression performance of fender is expressed by reaction force and energy absorption to deflection. Compression performance is different from the standard performance which is listed in a catalog due to environmental conditions and service conditions. Therefore, when designing fenders, it is required to consider influence factors on the above-mentioned effects and obtain modified compression performance multiplying to the standard compression performance by influence factors. Influence factors are applied according to the following classifications by the structure of facilities and service conditions. Factors are considered on those influences such as manufacturing tolerance, compression speed, ambient temperature, compression angle, repetition and fatigue, aging and creep. It is profitable to classify the cases in which some of factors should be considered depending on the level of influence of those factors to the facility design. CDIT guidelines proposed the following three cases [CDIT, 2018].

1) When considering only manufacturing tolerance:
   When structures are gravity type such as caisson type quay wall, sheet pile type quay wall and shelf type structures which are subjected to earth pressure and berthing impact force is supposed less than the design horizontal force by earthquake, and also when the allowable hull pressure of ship is more than 700 kN/m².

2) When considering velocity factor, temperature factor, angular factor and manufacturing tolerance:
   When structures are flexible such as single pile dolphin and jackets type which are the constructions of vertical piles and often berthing impact force is to be design horizontal force instead of seismic force, or when the allowable hull pressure of ship is less than 700 kN/m².

3) When considering motions of mooring ships and floating structures:
   When fender is to be designed considering motions of mooring ships and floating structures by means of numerical simulations, it is necessary to consider such influence factors as manufacturing tolerance, compression speed, ambient temperature, compression angle, repetition and/or fatigue, aging and creep.

Detailed descriptions of the above factors are given below.
3.2 Effect of Berthing Speed

Since rubber is a viscoelastic material and is dynamically sensitive, the compression performance varies with compression speed. Generally, reaction force rises in high compression speed. The Rated Performance Data is defined as standard performance in the guidelines of PIANC WG 33 [PIANC, 2002]. The Rated Performance Data is obtained by compression test with initial compressing speed of 0.15 cm/s and then decelerates and stops at the maximum displacement. The initial speed defined considering the actual design berthing velocity is taken about 0.1 to 0.15 m/s. However, it is difficult in practice to compress such fenders of 3 m in height and of which reaction force is nearly 6000 kN at 0.15 m/s initial speed. It is jointly prescribed in the guidelines of PIANC WG 33 on the methods to estimate Rated Performance Data from an examination of the low constant speed. Accordingly, the CDIT guidelines [CDIT, 2018] prescribes the standard speed (strain rate $V_0=0.01 \sim 0.3\%$/s) which is slow, constant and can be realised by manufacturers. Alternatively, the decelerating performance from 0.15 m/s can be calculated by the factors of scale model tests. The difference between the two guidelines is which condition is defined as the standard performance. The method prescribed in the CDIT guidelines is considered the practical way that can be verified by actual size fender while the PIANC WG 33 defines the standard performance close to the actual berthing; consequently, both design results will be equivalent. Since the velocity factor varies depending on rubber materials, it is necessary to obtain it for each material.

3.3 Effect of Temperature

Rubber is sensible to thermal characteristics; it is soft at high temperature and hardened at low temperature. Therefore, it is necessary to consider temperature factors in compression performance. Hardening becomes conspicuous especially at the low temperature less than -10 degrees Celsius, and also hardening remarkably differs depending on the rubber material. The standard temperature is prescribed as 23 degrees Celsius in the guidelines of PIANC WG 33 [PIANC, 2002]. Since rubber fender elements are thick, it takes a certain time to equilibrate the temperature inside. Procedures for adequate temperature stabilisation and determination of the temperature factor are prescribed in the guidelines of PIANC WG 33 [PIANC, 2002].

As for the design temperature, the highest and lowest statistical values of the daily average can be referred, but it is desirable to carry out on-site measurement in addition to the data of weather stations.

3.4 Effect of Berthing Angle

A berthing ship approaches to a quay with some angle between the quay line. Reaction force and energy absorption of rubber fender is less than the standard performance when it is compressed on an inclined face. It is necessary to clarify the design conditions concretely, because the angular performance is influenced by the longitudinal and lateral posture of fenders, oblique angle in the compression direction and size of fender panel and so on. It is also pointed out that flare angle of large container ships might become three to four times and more of berthing angle, therefore it must be avoided to berth at flare [Yamase, 2006].

3.5 Effect of Repetition Compression and Fatigue

Performance of rubber fender drops under repetition compressions. However, this performance dropping will recover within a certain time, therefore it is not necessary to consider this effect for few times compression at one ship berthing, but it is necessary to consider this effect when fenders receive repetition compression due to long-term motions of moored ship. If rubber fender receives repetition compression, the performance degradation will tend to converge saturate. However, performance suddenly drops at some point and eventually fender shall be destroyed. This test is called fatigue test and it can be carried out with a scale model or a small-size product.

3.6 Effect of Aging

Rubber deteriorates by the influence of heat, ultraviolet rays, oxygen and so on. Chemical deterioration over a long period has a hardening action and a softening action. It is reported from the survey results of used fenders that fenders gently harden with age [Akiyama, 2017a]. By aging, the physical properties of rubber deteriorate, then destruction by repetition fatigue will occur at an early stage. In prediction of service life of rubber fender by fatigue test, it is desirable to consider the effect of aging [Akiyama, 2018].
3.7 Break-In and Re-Hardening [CDIT, 2018]

Rubber fender should be compressed several times by the manufacturer before shipment so as to remove initial high reaction force. However, it was found that rubber molecules that had been broken by compression gradually recombine in long-term unloading conditions and the reaction force of the first compression after that increases noticeably. For example, when fender was stored for 1,000 days unloaded, reaction force for the first compression after that rises by about 25% against the standard performance. In general, it would not matter to ordinary berth operations which receive ships every few hours and days, but close attention is required when no ships have berthed for a long period or when introducing fenders that have been stored for a long time.

3.8 Other Factors Influencing Fender Performance

In addition to the above-mentioned influence factors, the production tolerance is determined from 0.9 to 1.1. And while creep is not an influence factor, it is one of the checkpoints for mooring design. When ships and/or floating structures are subjected to steady load such as wind load for a long time, fender deflection may progress with time and exceed the buckling point of fender. Therefore, it is essential to confirm the risk of fender buckling by creep in the evaluation of motions of moored ship.

4 TEST PROCEDURE OF FENDER

4.1 Testing Requirement and Objectives of Tests

There are various requirements of rubber fender tests, but the CDIT guidelines [CDIT, 2018] classifies them into the following three categories depending on the purpose of the test. Since rubber fender tests may give different results depending on the test procedure, the standard test methods are proposed in order to obtain appropriate results.

1) Quality verification test:
Tests which are conducted to assure the quality of products shipped to customers are called the quality verification tests. These tests are conducted on all or extracted products as necessary and the results of tests will be reported to customers. In some cases, customers or agents attend the tests at customers' request. Quality verification tests include quality control tests prescribed in the Standard Specifications for Port & Harbour Works [Ports and Harbours Bureau, Ministry of Land, Infrastructure, Transport and Tourism, hereafter MLIT, 2017] and in-line quality control tests and inspections voluntarily implemented by manufacturers before shipment.

2) Authentication test:
Tests which are conducted to obtain an objective certification for type approval on specific items of fender such as compression performances, material physical properties, durability and so on are called the authentication tests. The authentication tests and/or the evaluation of results are entrusted to a third-party institution. The authentication tests include the following cases.

a) Tests which are carried out by the third-party institutions on the submitted specimens (samples, products, etc.) from manufacturers.

b) Tests which are conducted by manufacturers under the witness of the third-party institutions.

c) A certificate is issued from the third-party institutions by evaluating the test report submitted by a manufacturer.

3) Development test:
Tests conducted by manufacturers to obtain various information and data to be listed in a catalog and technical materials are called the development tests. Manufacturers must specify clearly that tests have been conducted on the various influence factors under the conditions prescribed in the standard test method.

Testing requirements are categorized based on the design condition of fender as shown in Table 1 [CDIT, 2018].
Table 1: Testing requirements for each factor at design conditions

<table>
<thead>
<tr>
<th>Test for factors</th>
<th>Fender design</th>
<th>Design considering manufacture tolerance</th>
<th>Design considering Speed factor, Temperature factor, Angular factor and Manufacturing tolerance</th>
<th>Design based on mooring simulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physical property test</td>
<td>Quality verification test</td>
<td>Quality verification test</td>
<td>Quality verification test</td>
<td>Quality verification test</td>
</tr>
<tr>
<td>Compression performance test</td>
<td>Quality verification test</td>
<td>Quality verification test</td>
<td>Quality verification test</td>
<td>Quality verification test</td>
</tr>
<tr>
<td>Speed factor test</td>
<td>Not available</td>
<td>Development test</td>
<td>Development test</td>
<td>Development test</td>
</tr>
<tr>
<td>Temperature factor test</td>
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<td>Development test</td>
<td>Development test</td>
<td>Development test</td>
</tr>
<tr>
<td>Angular factor test</td>
<td>Not available</td>
<td>Development test</td>
<td>Development test</td>
<td>Development test</td>
</tr>
<tr>
<td>Durability test</td>
<td>Authentication test</td>
<td>Authentication test</td>
<td>Authentication test</td>
<td>Survey &amp; Development test</td>
</tr>
<tr>
<td>Evaluation for aging</td>
<td>Not available</td>
<td>Not available</td>
<td>Survey &amp; Development test</td>
<td>Authentication test</td>
</tr>
<tr>
<td>Repetition test</td>
<td>Not available</td>
<td>Not available</td>
<td>Development test</td>
<td>Development test</td>
</tr>
<tr>
<td>Creep test</td>
<td>Not available</td>
<td>Not available</td>
<td>Development test</td>
<td>Development test</td>
</tr>
</tbody>
</table>

4.2 Physical Properties of Rubber

The physical properties of rubber are important because rubber fender receives high strain in the harsh environment of coastal areas. For the physical property tests, tensile strength tests, elongation tests, hardness measurement tests and ozone resistance tests are conducted in conformity to the JIS and/or ISO. The Standard Specifications for Port & Harbour Works [MLIT, 2017] prescribes heat aging tests and the allowable differences for tensile strength and hardness before and after the heat aging tests. The CDIT guidelines prescribes rubber physical material tests on quality verification, the collection of test specimens from the same production lot used for actual product, retest procedure at the time of failure and the submission of the test specimens to customer upon request.

4.3 Compression Performance Test

Since a compression performance test is the fundamental test to determine the standard performance of rubber fender, the preparation and the procedures are specifically defined [CDIT, 2018]. The standard compression performance test shall be applied to any of the quality verification tests, the authentication tests and the development tests.

The procedure of the standard compression performance test are as follows.

1) Temperature stabilisation:
   Keep the standard temperature (23±5 degrees Celsius) for estimated necessary stabilisation time.

2) Break-in compression:
   Make three times or more compressions up to the maximum deflection as recommended by manufacturer.

3) Recovery time:
   Keep unloaded for one hour or more at the standard temperature.

4) Final compression:
   Make one compression up to the maximum deflection or more at the standard speed (Strain rate $V_0=0.01$ to 0.3 %/s).

The CDIT guidelines prescribes the additional procedures for quality verification tests: number of sampling specimens and retest procedure in case of failure. The CDIT guidelines advises that all products be compressed at least once up to the maximum deflection in order to remove the initial high reaction force, for such structures as piers when the horizontal force cannot be ignored and when allowable hull strength is less than 700 kN/m². The PIANC WG 33 [PIANC, 2002] guidelines prescribes this as break-in...
compression, and break-in compression is mandatory for all fenders with reaction force of 100 tonnes or more which shall be installed on single pile structures or pile supported pier structures.

4.4 Test to Determine the Velocity Factor

The velocity dependency test is one of development tests for obtaining the velocity factor due to dynamic characteristics of rubber. The specimen is either a scale model or a full-size product, and there are two different test protocols prescribed in the guidelines of PIANC WG 33 [PIANC, 2002]. The velocity factor is obtained by dividing the performance (reaction force and energy absorption) under that speed by the performance at the standard speed (0.01 to 0.3 %/s). In order to prevent the influence of compression history in the result, it is necessary to pay attention so that both are new or have the equivalent compression history.

1) CV Test Method (Constant Velocity test):
Compress up to the maximum deflection at a constant speed in accordance with the final compression test described above 5.3 4). The different strain rates of compression within the range of 0.01 to 50 %/s are applied.

2) DV Test Method (Decreasing Velocity test):
In the final compression described above 5.3 4), compress at various initial speeds and nearly stops at the maximum deflection. Change the initial strain rate within the range of 0.01 to 50 %/s. The performance of deceleration compression with an initial speed of 0.15 m/s corresponds to the Rated Performance Data specified in the guidelines of PIANC WG 33 [PIANC, 2002]. The methods of decreasing speed can be linear-decreasing, sinusoidal-decreasing and the decreasing accompanied by energy absorption, but there are no significant differences among those ways [CDIT, 2018].

4.5 Test to Determine the Temperature Factor

The temperature dependency test is one of development tests for obtaining the temperature factor due to thermal characteristics of rubber. The specimen can be a scale model or small size product and it is stored for the time determined by the maximum thickness of the rubber part in the thermostatic environment to keep the rubber temperature constant. The control of ambient temperature and its recording are also described in PIANC WG 33 [PIANC, 2002]. Compressing the specimen up to the maximum deflection at the standard speed and temperature (23±5 degrees Celsius) in accordance with the final compression test described above 5.3 4), the temperature factor is taken as 1.0. The temperature range shall be from -30 to 50 degrees Celsius with intervals of 10 degrees Celsius, with paying attention so as not to be affected by compression history. In addition, temperature factor and velocity factor have a certain relationship of the WLF equation [Williams, 1955], so it is possible to estimate velocity factors from temperature factors by interpolation or extrapolation among strain rates [CDIT, 2018].

4.6 Test to Determine the Angular Factor

The angular compression test is one of development tests for obtaining oblique compression characteristics. Compressing the specimen up to the maximum deflection at the standard condition in accordance with the compression test described above 5.3 4), the performance of the final compression at the target angle (± 1 degree) are taken as the angular factors to the standard angle. Here again, additional care should be taken not to be influenced by the compression history if one specimen is used for different angles. The initial performance near the first contact point of angular compression can be neglected for convenience since it is a small value that is the force affected by the rotation of fender top [CDIT, 2018].

4.7 Durability Test (Fatigue)

Evaluation of durability is usually called a repetition compression test and/or fatigue test, which repeatedly gives a constant strain to rubber fender. For development tests, scaled models are often used, but authentication tests using small size products are prescribed. In the guidelines of PIANC WG 33 [PIANC, 2002] and in the Standard Procedure to Durability Test for Rubber Fender Units of SCOPE (Service Center of Port Engineering, hereafter SCOPE, 2012), the 3,000 repetition compression to the maximum deflection without any external temperature controlling is required to the specimen which has the same basic design
as the product described in the manufacture’s catalog. It is necessary to confirm that no visual cracks are generated and that there is no significant performance degradation between before and after the test.

5 DETAIL DESIGN OF FENDER SYSTEM

5.1 Fender System Design

In designing larger fenders, a significant portion of the total cost is taken by steel parts such as a fender panel and chains. Since early deformation or breakage of steel parts may cause unexpected damage to ship hulls, it is important to design them properly.

5.2 Fender Panel

Size of a fender panel is determined considering the allowable hull pressure, the relative position of water level, ship hull and fender and so on. In order to perform the structure design of fender panel, the maximum bending moment is calculated assuming a state where the forces and the rotational moments on the fender panel are balanced.

5.3 Chains

Chains greatly influence the bending moment generated in the fender panel depending on the place where they are installed, and greatly affect the performance of the entire fender system. Fender specifications occasionally have to be revised depending on the chain locations when the tension is obtained by the balance between forces and rotational moments on the fender panel at angular compression. In some case, due to safety concerns, anti-fouling chain for prevention of breakage of mooring rope would be installed.

5.4 Fixings

Most of rubber fender is fixed to quay wall by anchor bolts. The tensions by angular compression and shearing forces by ship’s surge, heave and roll act on anchor bolts, but the action of those forces varies depending on type and shape of fender, so the specification of anchor bolts is designed by the manufacturer and described in the catalog.

5.5 Corrosion Control

To prevent corrosion of steel, methods such as the coating method and the cathodic protection method are applied. Heavy-duty coating (zinc rich primer plus epoxy resin: total film thickness of 320 to 450 μm) is mainly applied to fender panel coating, and hot dip galvanising (molten zinc adhesion amount of minimum 550 g/m$^2$ or minimum thickness of 76 μm) is used for chain coating. The details are prescribed in the Manual on Corrosion Prevention and Repair for Ports and Harbour Steel Structure [CDIT, 2009].

6 LONG TERM AGING OF FENDER

6.1 Visual Evaluation of Aged Fenders [CDIT, 2013]

Degradation of rubber fender contains phenomena which can be observed visually such as cracks and wear, and also invisible phenomena from the appearance such as deterioration of material, internal cracks and others. For the visual evaluation, a method to rank the deterioration rate by measuring cracks, wear and abrasion and so on is proposed as follows.

1) Rubber fender body:
   Crack, cut, delamination, etc.: a coefficient obtained by dividing the total length of broken parts by the representative dimension (height or length).
   Wear, chipping, missing, etc.: a coefficient obtained by dividing the damaged area by the representative area (ex. contact area).
2) Fender panel, chain, fixings: 
Rust, bending, cutting, looseness, etc.: three deterioration ranks judged by reference photographs. 

Based on above coefficients and ranks, the countermeasures such as replacement, touch-up, follow-up observation and others are recommended.

6.2 Aging of Performance During Long-Term Use [Akiyama, 2017b; Akiyama, 2018]

The actual used fenders were picked up from the sites and the compression performance and the material properties were investigated. The examples of results are shown in Figure 4.

The aging factor $C_{agr}$ is defined as equation (3) [Akiyama, 2018].

$$C_{agr} = \frac{\text{Reaction force of used fender}}{\text{Reaction force of fender catalog}}$$ (3)

![Figure 4: Aging factor of used fender (Cell type)](image)

Although the reaction force varies as shown in Figure 4, it increases moderately in service years. In the compression test, the three deterioration modes such as crack expansion, abnormal deformation and abnormal high reaction force were evaluated by ranking in order to determine whether reuse was possible. Fenders which had been in use more than 30 years were generally judged to be non-reusable. This age is considered the average practical longevity of these fenders based on actual records. While it cannot be seen visually, rubber material was found to have hardened over time. Both tensile strength and breaking elongation decrease remarkably in the depth of 50 to 100 mm from the outer surface.

In order to predict aging of fender performance, it is possible to use estimation by heat aging tests of scale model and calculation by FEM.

1) Aging prediction by heat aging test of scale model: 
Akiyama et al. applied a thermal accelerated aging to 100-mm scale models at 80 degrees Celsius and predicted the aging factor by the Arrhenius equation as plotted in Figure 4 in addition to the actual used fenders. The aging factors are in good agreement between the scale model and the used fenders. Moreover, after the accelerated aging equivalent to more than 68 years, the fender models broke by the first compression. This suggests the limit of rubber material for fender [Akiyama, 2017b].
2) Aging prediction by FEM analysis:
   The progress of FEM calculation technology has been remarkable, and even with general-purpose software on the market it has become possible to calculate large deformation of nonlinear material by using super-elastic model. In order to calculate the performance by FEM adequately, it is necessary to properly estimate the aging of physical properties of rubber. Akiyama et al. cut the rubber sample out of the old fender after 28 years of use and collated the physical property with the rubber sample after accelerated aging equivalent to 28 years by the Arrhenius equation to verify a reasonable age prediction. If the aging of physical properties can be predicted, it would become possible to calculate the performance change of an arbitrary shape by FEM and estimate the reasonable service life by scale model.

7 STANDARDS AND GUIDELINES FOR FENDER

7.1 Technical Standards and Commentaries for Port and Harbour Facilities in Japan

The most important technical standard on rubber fender in Japan is ‘Technical Standards and Commentaries for Port and Harbour Facilities in Japan’ [PHAJ, 2018] which was supervised by MLIT. This standard mainly focuses on designing and testing methods of rubber fenders for ship’s berthing and mooring facilities installed in ports and harbours and prescribes the safety assessment of rubber fenders used for floating structures. When designing rubber fenders to be used in ports, it is possible to apply the method described in this standard.

7.2 Standard Specifications for Port & Harbour Works

MLIT issued the Standard Specifications for Port & Harbour Works [MLIT, 2017] which specifies necessary matters such as materials and construction regulations in order to establish unified interpretation and operation of port construction ordered by the Japanese government. As to rubber fender, this standard describes the required items such as the physical properties like elongation, strength and hardness, the verification of proof of durability, acceptable range of dimensions and method of compression performance test.

7.3 Standard Procedure to Durability Test for Rubber Fender Unit (SCOPE)

SCOPE is an institution that conducts quality review and certification of port and airport construction materials. In response to the addition of the approval of durability test of rubber fender in the Standard Specifications for Port & Harbour Works, SCOPE issued ‘Standard Procedure to Durability Test for Rubber Fender Units’ [SCOPE, 2012] and specified the durability test method of rubber fender. In accordance with this standard, SCOPE conducts a rubber fender durability certification business to confirm the compatibility with quality standards on the durability of rubber fender produced in Japan. The judging items are durability, stability of supply, etc. and the test specification is the same as explained in 5.7.

7.4 Standard Procedure to Evaluate Imported Fenders (SCOPE)

SCOPE conducts quality assessment and certification business of foreign-made materials to secure the quality of construction materials produced in foreign countries and to promote use for domestic construction. The target foreign materials are rubber fender, aluminum alloy anode, anchor chain, etc. and items to be examined are quality, performance, stability of supply, etc. Especially for rubber fender, evaluation of durability by repetitive compression test mentioned in 8.3 is an important item.

7.5 Guidelines by CDIT

Coastal Development Institute of Technology (CDIT) is an institution that conducts research and dissemination of technology related to development, utilisation, conservation and disaster prevention of coastal areas. CDIT published ‘Maintenance Guidelines for Maritime Fender Systems’ [CDIT, 2013] and ‘Guidelines for Design and Testing of Rubber Fender Systems’ [CDIT, 2018]. In the former, a simple method
of evaluating aged deterioration, damage, etc. of rubber fender by visual inspection and determining countermeasures such as replacement is presented. In the latter, the design method of rubber fender considering various influence factors such as manufacturing tolerance and velocity factor, etc. and the test method of rubber fender categorised into three types of quality verification test, authentication test and development test are detailed. These guidelines play an important role in complementing the technical standards in the design, construction and maintenance of rubber fender at the ports and harbors in Japan.

8 UTILISATION OF RUBBER FENDERS AT OTHER FACILITIES

8.1 Applications to Floating Structures

Rubber fenders are not only used for facilities for ship’s berthing and mooring, but also are used for mooring of floating structures such as floating oil storage tanks, floating bridges, floating piers, floating breakwaters. As representative examples, floating oil storage bases and a floating bridge are introduced in this chapter.

8.2 Fenders for Mooring the Floating Tanks in Oil Storage Base

For the purpose of national oil stockpiling, the Kamigoto Oil Storage Base and the Shirashima Oil Storage Base started operation in 1989 and 1997, respectively [Ikegami, 1994] [Ito, 1994]. Figures 5 and 6 show conceptual scheme of mooring oil storage tanks.

![Figure 5: Mooring system: Kamigoto Base](image)

![Figure 6: Mooring system: Shirashima Base](image)

The Kamigoto base has five of 880 Mega liter storage tanks supported by 40 units of 3,000 H and 20 units of 2250H Cell type fenders. The Shirashima base has eight of 700 Mega liter storage tanks supported by 128 units of 2,500 H fenders. Rubber fenders are extracted every 5 to 10 years for the compression test and the material evaluation to check the durability. Based on this practice, a lot of knowledge on aging of rubber fender has been acquired [Akiyama, 2018].

8.3 Fenders for Mooring the Floating Bridge

Two artificial islands, Yumeshima and Maishima in the port of Osaka, are bridged by a floating movable bridge [Maruyama, 2002]. As shown in Figure 7, this bridge is floating on the river Aji with two piers on each pontoon, and 24 units of Cell type fenders (2,500 H) are installed at both ends of the bridge girder and being moored to the reaction walls as shown in Figure 8. In emergency when the main channel is out of service, the reaction wall inverts, the floating bridge is unmoored, then the entire bridge rotates around Maishima as a fulcrum by tugboats for large ship navigation.
9 CONCLUSIONS

In Japan, technologies related to rubber fenders, especially design methods and test methods, have been generally established with the exception of some parts such as the application of the reliability design method. It is expected that these technologies related to rubber fender will be disseminated and utilised worldwide, not only in Japan, to contribute to the construction of safe and reliable port facilities in the future.

10 REFERENCE


Service Center of Port Engineering (SCOPE) (2012): “Standard Procedure to Durability Test for Rubber Fender Units”.


SUMMARY

Rubber fender is an important ancillary equipment in the port and harbor facilities which is used when ship is berthing and being moored. It is a structural product mainly composed of rubber and is used under conditions of ship’s berthing and mooring, so advanced techniques are required for its design and testing. In this paper, rubber fender technologies in Japan including design, performance, testing, history of development and upsizing, long-term performance evaluation, and current standards and guidelines are introduced.

RESUME

Les défenses en caoutchouc sont des équipements auxiliaires importants dans les installations portuaires. Elles sont utilisées lors de l’accostage des navires et lorsqu’ils sont amarrés.

Ces équipements structurels composés principalement de caoutchouc sont soumis aux contraintes spécifiques d’accostage et d’amarrage des navires, de sorte que des techniques de pointe sont nécessaires pour leur conception et pour leurs essais.

Dans cet article, nous présentons les technologies des défenses en caoutchouc au Japon, en termes de conception, performances, tests, ainsi que l'histoire de leur développement et de leurs évolutions, l'évaluation de leurs performances à long terme, et finalement présente les normes et directives en vigueur.

ZUSAMMENFASSUNG


RESUMEN

Las defensas de caucho son una parte importante del equipamiento portuario necesario mientras el buque atrae y cuando se encuentra amarrado. Se trata de un elemento que básicamente se construye con caucho y que requiere tecnologías avanzadas en lo que se refiere tanto a su diseño como a su validación mediante ensayos. En este artículo se recogen las técnicas que se emplean en este sentido en Japón, incluyendo condiciones de diseño, ejecución, ensayo, comportamiento a largo plazo, así como referencias a la actual normativa y pautas generales para su desarrollo.
THE ‘FRONTIER FISHING GROUND ENHANCEMENT AND DEVELOPMENT PROJECT’ IN THE EEZ OF JAPAN

by

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Mots-clés : zone de pêche, récif artificiel, haut-fond artificiel, crabe des neiges, carangues

1 TREND IN JAPAN’S FISHERIES AND THE BACKGROUND OF THE PROJECTS.

According to estimates by the United Nations, the world population is expected to reach 8.1 billion in 2030. More food is needed in the future. But FAO predicts that world fishery supply will not increase in the future.

In Japan, the fishery production volume has declined rapidly from its peak in 1984 (12.82 million tonnes) as shown in Figure 1. And it continues to decrease. In particular, the offshore fishery production volume has been greatly reduced.

The result of the FY2017 stock assessment in the water around Japan (for 84 stocks of 50 species) shows that resource levels are high in 14 stocks, moderate in 31 stocks and low in 39 stocks.

As for major 37 stocks of 15 species closely linked to the lives of people, resource levels are high in 8 stocks, moderate in 16 stocks and low in 13 stocks as shown in Figure 2.
2 THE NECESSITY OF THE ‘FRONTIER FISHING GROUND ENHANCEMENT AND DEVELOPMENT PROJECT’

The waters of Japan have a wealth of fishery resources. Northwest Pacific including the waters around Japan account for 25% of global fishery output. Japan has wide territorial waters and the EEZ (Exclusive Economic Zone). The size of Japan’s EEZ is 12 times larger than the national land and the 6th in the world (see Figure 3). Warm currents and cold currents are flowing along the long coast of Japan, and the coast of Japan has many complicated forms, as rias coastlines. Therefore, the waters of Japan have high biodiversity, such that there are 50 marine mammalians (127 species in the world) and about 3,700 species of saltwater fish (15,000 species in the world).

On the other hand, fishing grounds have not been improved in the waters of Japan sufficiently. In this situation, the Japan Fishery Agency has emphasised the need to enhance offshore fisheries resources in the EEZ of Japan in the Basic Plan for Fishery.

Furthermore, the 'Fishing Port and Fishing Ground long-term development plan of Japan' is part of the Japanese Government's effort to enhance and develop fishery grounds in Japanese waters including the EEZ. Based on the plans, Japan Fishery Agency newly started the fishing ground improvement project in order to promote the improvement of fishing grounds in the EEZ of Japan in 2007.

Figure 3: The area of EEZ of Japan
3 THE OUTLINE OF THE FRONTIER FISHING GROUND ENHANCEMENT AND DEVELOPMENT PROJECT IN THE EEZ

To conserve and propagate fisheries resources in the waters around Japan, Japan Fishery Agency has been constructing artificial reefs in the EEZ since 2007.

The following conditions are necessary for the project.
1. The artificial reefs are located in the EEZ (Exclusive Economic Zone) of Japan.
2. The resources of target fisheries creatures are managed by TAC (Total Allowance Catch) or TAE (Total Allowance Effort).
3. Target fisheries creatures are conserved around the artificial reefs.
4. The project is expected to have a remarkable effect.

As shown in Figure 4, the Japan Fishery Agency is promoting projects in four areas: ① Nursery reefs in the area of Western Japan Sea (off the coast from Hyogo Prefecture to Shimane Prefecture), ② Two artificial upwelling fishing grounds in Oki channel (off the coast from Tottori Prefecture to Shimane Prefecture), ③ An artificial upwelling fishing ground in Tsushima channel (Nagasaki Prefecture), ④ An artificial upwelling fishing ground in Osumi channel (Kagoshima Prefecture).

In 2015, Japan Fishery Agency completed the project of ⑤ An artificial upwelling fishing ground in the offshore area of Goto Islands (Nagasaki Prefecture). This is the first completed project.

4 REGIONAL OVERVIEW OF EACH PROJECT

4.1 Nursery Reefs in the Area of Western Japan Sea

4.1.1 Regional Features in the Area of the Western Japan Sea

The Western Japan Sea has a large continental shelf with a depth of less than 200 m. It is a good fishing ground for flathead flounder and snow crab as shown in Figure 5. However, the catch of flathead flounder decreased from about 8,000 tonnes in 1981 to about 1,000 tonnes in the 1990s. Currently, the annual catch is ranging from 2,000 to 3,000 tonnes, as shown in Figure 6.
The catch of snow crab was over 10,000 tonnes from the latter half of 1950 to the beginning of 1970. But the current stock condition indicates there are only about half as many females and about one-third as many males compared with 1970. Currently, the annual catch is ranging from 2,000 to 4,000 tonnes as shown in Figure 6. For this reason, the Japanese Government prepared a fishery resource management plan and manages fishery resources together with stakeholders.

4.1.2 The Purpose of the Project in the Area of the Western Japan Sea

The population of snow crab in the Western Japan Sea area has been in significant decline in recent years; initiatives to recover the population are urgently required. It is also necessary to keep the population of flathead flounder at a stable level. Therefore, the Japan Fishery Agency is promoting the creation of nursery reefs to conserve snow crab and flathead flounder from 2007 to 2021 in order to enhance the fisheries resources in the area of Western Japan Sea of Japan’s EEZ.

4.1.3 Disposition and Structure of Nursery Reefs

In order to increase populations of snow crab and flathead flounder, 32 nursery reefs will be created. The location of the nursery reefs is as shown in Figure 7. The size of a nursery reef is 4 square kilometres, as shown in Figure 8. A reef consists of about 100 concrete reef blocks and often contains some steel reefs, depending on the location. The size of the nursery reef and the distance between blocks are decided in consideration of the ecology of the snow crab.
Figure 7: Location of nursery reefs

Figure 8: Typical structure of a nursery reef
Under the severe currents of the Western Sea of Japan, we need to place the nursery reefs at a fixed position in water depths ranging from 200 to 500 m. We succeeded in placing them at a depth of 500 metres in 2018 by using the work ship that has many thrusters, DPS (Dynamic Positioning System), and a transponder.

The procedures for loading and placing nursery reefs are shown in Figures 9, 10 and 11.

The procedure of placing the reef blocks is as follows:

1. First, the work ship moves to the required position.
2. We begin to submerge a reef block (or steel reef) by crane. However, reef block is often moved by ocean current.
3. When the reef block almost reaches the seafloor, we check the latest position by the transponder that is mounted on the crane hanger. And we move the reef block to the planned position using the crane.

Nursery reefs are placed in EEZ far away from the land. If the wave condition gets worse, we cannot avoid this. So, we require the sufficient time that have calm wave condition in order to place the nursery reefs. Therefore, we need to load the reef blocks at midnight and also depart at midnight so that we arrive before dawn and start placing the blocks at sunrise.

Figure 9: Procedure of placing nursery reefs (center-right: about transponder)

Figure 10: Loading nursery reefs

Figure 11: Placing nursery reefs

Reef blocks must be placed within 30 metres of the planned position. By using a working ship that has DPS and transponder, we succeeded in placing the reef blocks within 10 metres of the planned position in 2018, as shown in Figure 12.
4.1.4 Effect of the Nursery Reefs

By 2017, 20 nursery reefs had been successfully created. Japan Fishery Agency has investigated the levels of snow crab and flathead flounder inside and outside the completed nursery reefs as well as the situation of the reefs by ROV (Remotely Operated Vehicle).

The results of the investigation revealed that more snow crabs inhabit the nursery reefs than the area outside, as shown in Figure 13. We expect that the population of snow crabs will increase inside of the nursery reefs and then expand to the area outside the reefs.

4.2 Artificial Upwelling Fishing Ground in the Offshore Water of the Goto Islands

4.2.1 Regional Features in the Offshore Water of the Goto Islands

The Goto Islands are located on the east side of the East Chinese Sea and to the west of the Kyushu region. The area around Goto Islands is a good fishing ground for jack fish (maaji), chub mackerel (masaba), Japanese sardine (maiwashi) and so on, due to a large continental shelf with a depth of less than 200 m and the warm Tsushima current.
The catch trend of target species (jack fish, chub mackerel, Japanese sardine) is shown in Figure 14. Catch amounts of jack fish in the warm Tsushima current area were maintained at more than 200,000 tonnes from 1993-1998 but decreased to 130,000 tonnes in 2008. Catch amounts of chub mackerel had been increasing since 1993, reaching 410 thousand tonnes in 1996. However, there was a sharp decline to 120,000 tonnes in 2008. In addition, catch volumes of the Japanese sardine are at low levels in recent years.

For this reason, Japan Fishery Agency has made a fishery resource management plan in this area since March in 2009 in order to restore jack fish, chub mackerel and Japanese sardine populations.

4.2.2 Purpose of the Regional Project at the Western Offshore Water of the Goto Islands

The jack fish, chub mackerel and Japanese sardine populations need to recover in order to realise a thriving fishing ground in the Western offshore waters of Kyushu.

Therefore, Japan Fishery Agency is promoting the construction of an artificial upwelling fishing ground to increase the resources in the EEZ of the Western waters of Kyushu from 2010 to 2015.

4.2.3 Disposition and Structure of the Artificial Upwelling Fishing Ground

We decided to create an artificial upwelling fishing ground by a mound reef which is placed on the ocean floor in order to increase fishery resources and gather fishes.

The mechanism of the upwelling fishing ground is shown in Figure 15.

The surface layer of the water has a lot of basic production. However, the surface layer of the water often lacks nutrients in summer. A mound reef therefore carries lower layer water that contains a lot of nutrients to the surface layer by the upwelling. It therefore increases fishery resources by enhancing basic production of waters.
The location and structure of the upwelling fishing ground (mound reef) is shown in Figures 16 and 17. It is approximately 250 m long, 125 m wide and 30 m high. The core of the mound reef consists of stones, and its outside consists of concrete reef blocks.

The size of the mound reef is decided in consideration of the depth of water and the upwelling.

The mound reef is made by the procedure described below and shown in Figure 18.
At first, we submerge stones, each weighing 1 tonne, to form the core of the mound reef.
Next, we submerge the reef blocks and form the whole of the mound reef.

We require that the constructed mound reef has larger scale than planned scale. We confirmed the size of the constructed mound reef using a Narrow Multi-Beam Sounder, as shown in Figure 19.
4.2.4 Effect of the Artificial Upwelling Fishing Ground

This project was completed in October 2015. The Japan Fishery Agency has been investigating the occurrence of photosynthesis, the generation of planktons, the size of target fishes and gathering level of fishes around it. From the results of the investigation, the following effects have been confirmed.

a) Improvement of Marine Environment and Basic Production

The results of the investigation of the marine environment and the basic production are shown in Figure 20.

Around the mound reef, nutrient concentration is constant from the bottom to the blight layer. We therefore consider that nutrients are being upwelled by the mound reef. Furthermore, the volume of benthos increased on the bottom around the mound reef by 5 times since the reef was constructed. Benthos use organic matter such as plankton carcasses as food. Thus, we consider that the upwelling enhances photosynthesis by plankton and generates plankton around the mound reef. We also consider that the enhancement of the basic production of waters have the effect of increasing the fishery resources.

![Figure 20: Results of investigation on improvement of marine environment and basic production](image)

b) Increase in Fishery Resources and Gathering Fishes

We investigated the weight of jack fishes around the mound reef. The result shows that the weight of jack fishes in the mound reef area is heavier than the average weight in Tsushima-Warm-Current-Stocks, as shown in Figure 21.

Furthermore, we estimated the volume of jack fishes that gathered in the mound reef area by using ROV. The result shows that jack fishes gather around the mound reef as much as we expected (3,488.6 t/year, as shown Figure 22).

We consider that the upwelling by the mound reef provides food for many fishes and has the effect of increasing fishery resources.
Fig. 21: Weight of Jack fish around mound reef, compared to average weight in Tsushima-Warm-Current-Local-Stocks

Fig. 22: Example of generation of zoo plankton and gathering fish by using echo-sounder and estimation of volume of Jack fish that gathered in mound reef area

5 CONCLUSION

The completed fishing ground of the project produced good results and is highly evaluated by related fishermen.

Based on this project, we have been promoting three projects of upwelling fishing grounds by mound reefs in the EEZ of Japan. The outlines of these projects are shown in Figure 23.

We expect that these fisheries grounds will lead to an increase in the basic production of waters, increase in fishery resources, and an increase in catch amounts.

We would like to thank the many concerned fishermen, local government, construction companies and others for their understanding and cooperation in implementing Frontier Fishing Ground Enhancement and Development Projects in each region.
Figure 23: Outlines of other projects (Oki channel, Tsushima channel, Osumi channel)

6 REFERENCES

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- Basic Plan for Fishery [Japan Fishery Agency, 2017]
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  - Artificial upwelling fishing grounds at Oki channel
  - An artificial upwelling fishing ground at the Tsushima channel
  - An artificial upwelling fishing ground at the Osumi channel
  - An artificial upwelling fishing ground at the Western Goto Islands

SUMMARY

To recover and increase production capacity of the marine resources in the EEZ of Japan, Japan Fishery Agency has promoted projects of artificial reef construction since 2007. In 2015, Japan Fishery Agency completed the project of an artificial upwelling fishing ground in the offshore water of Goto Islands (Nagasaki Prefecture), first.

Japan Fishery Agency is promoting projects in four areas: ① Nursery reefs in the area of Western Japan sea (off the coast from Hyogo Prefecture to Shimane Prefecture), ② Two artificial upwelling fishing grounds in Oki channel (off the coast from Tottori Prefecture to Shimane Prefecture), ③ An artificial upwelling fishing ground in Tsushima channel (Nagasaki Prefecture), ④ An artificial upwelling fishing ground in Osumi channel (Kagoshima Prefecture).

We conducted an investigation in the Western Japan Sea and the offshore area of Goto Islands. The results are as follows:

1. In the Nursery reefs in the Western Japan Sea, which have been partially completed, more snow crabs exist than in the area around the reefs. We expect that the population of snow crabs in the reefs will increase and their growth will expand to the area outside the reefs.
2. In the project area to the west of Goto Islands, more jack fishes have gathered than we expected in the project plan. And the weight of jack fishes in the project area is heavier than that around the area. We consider that the upwelling by the mound reef is providing food for many fishes and has the effect of increasing fishery resources.

RESUME

Pour restaurer et augmenter la capacité de production de ressources marines dans la zone économique exclusive (ZEE) du Japon, l'agence japonaise de la pêche encouragé les projets de construction de récifs artificiels depuis 2007.

En 2015, cette agence a achevé un premier projet d’amélioration artificielle d’une zone de pêche au large des îles Gotō (Préfecture de Nagasaki).

L’agence japonaise de la pêche a aidé des projets dans quatre régions :
① Les récifs Nursery dans la mer du Japon (au large des côtes s’étendant de la préfecture de Hyogō à celle de Shimane) ② Deux récifs artificiels dans la zone de pêche du canal Oki (au large des côtes s’étendant de la préfecture de Tottori à celle de Shimane) ③ Un récif artificiel dans la zone de pêche du canal Tsushima (préfecture de Nagasaki) ④ Un récif artificiel dans la zone de pêche du canal Osumi (préfecture de Kagoshima).

Une enquête a été menée sur les équipements de la mer du Japon et de la zone au large des îles Gotô. Les résultats sont les suivants :

1. Dans les récifs Nursery de la mer du Japon, en partie réalisés, les crabes des neiges sont plus nombreux que dans la zone alentour. Une augmentation de la population de crabes des neiges dans les récifs et attendue, et cette augmentation s’étendra aux zones situées autour des récifs.
2. Dans la zone à l’ouest des Îles Gotō, il a été constaté un nombre de carangues (poisson démersale) plus important que prévu dans le projet. La densité de carangues y est plus forte que dans les zones alentour. Nous considérons que le récif artificiel fournit de la nourriture à de nombreux poissons, ce qui a pour effet d’accroître les ressources de la pêche.

ZUSAMMENFASSUNG


Die japanische Fischereibehörde fördert Projekte in vier Bereichen: ① Riffe für Fischbrut im Gebiet des westjapanischen Meeres (von der Küste der Hyogo-Präfektur bis zur Küste der Shimane-Präfektur), ② zwei künstliche Auftriebs-Fischgründe im Oki-Kanal (von der Küste der Tottori-Präfektur bis zur Küste der Shimane-Präfektur), ③ einen künstlichen Auftriebs-Fischgrund im Tsushima-Kanal (Nagasaki-Präfektur), ④ einen künstlichen Auftriebs-Fischgrund im Osumi-Kanal (Kagoshima-Präfektur).

Es wurden Untersuchungen im west-japanischen Meer und im Küstengewässer der Goto-Inseln durchgeführt. Die Ergebnisse sind wie folgt:


RESUMEN

Para recuperar e incrementar la capacidad de producción pesquera en la Zona Económica Exclusiva (ZEE) de Japón, la Agencia de Pesca de Japón ha venido desarrollando desde 2007 proyectos de construcción de arrecifes artificiales. En 2015, la Agencia de Pesca completó por vez primera un proyecto de generación de un arrecife artificial en la zona pesquera de las islas Goto (prefectura de Nagasaki).

La Agencia de Pesca de Japón desarrolla actualmente proyectos en cuatro áreas: ① Arrecifes que actúen como viveros en la zona Oeste de Japón (desde la prefectura de Hyogo a la prefectura de Shimane), ② dos afloramientos artificiales en zonas pesqueras del canal de Oki (desde la prefectura de Tottori a la prefectura de Shimane), ③ un afloramiento artificial en la zona pesquera del canal de Tsushima (prefectura de Nagasaki), ④ un afloramiento artificial en la zona pesquera del canal de Osumi (prefectura de Kagoshima).

Tras el desarrollo de las investigaciones en la zona Oeste de Japón y el área de las islas Goto, los resultados han sido los siguientes:

1. En los arrecifes que actúan como viveros en la zona Oeste de Japón, que han sido parcialmente finalizados, han aparecido un mayor número de cangrejos de las nieves. Se espera que la población de este tipo de cangrejos se incremente y se expandan a zonas más allá de los arrecifes.

2. En el proyecto de las islas Goto, se ha detectado un incremento del número de jureles, respecto de lo inicialmente estimado. Y el peso de estos peces es superior a los ejemplares existentes en zonas cercanas. Se entiende que estos afloramientos de arrecifes artificiales proveen de comida a los peces, lo que conlleva un incremento en los recursos pesqueros de la zona.
INTRODUCTION OF COUNTERMEASURES AGAINST THE DEFORESTATION OF SEAWEED BEDS ‘ISOYAKE’ IN JAPAN

by

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Keywords: seaweed bed, barren ground, isoyake, herbivorous fish, sea urchin, recovery measurements, adaptive management, structural measures, non-structural measures

Mots-clés : sols stériles, gestion adaptative, poissons herbivores, oursins, bancs d’algues

1 STATUS OF MACROPHYTE BEDS IN JAPAN

In Japan, macrophyte beds are called ‘Moba’, which consist of seaweed and seagrass beds in shallow coastal zones. They include kelp forests (Konbu-ba), Eisenia and/or Ecklonia beds (Arame-Kajime ba), Sargassum beds (Garamo-ba), and eelgrass beds (Amamo-ba) (Photo 1), and generally occur as mixed-species beds rather than mono-species ones. Macrophyte beds have important ecosystem services and have direct and indirect benefits to human society [Barbier et al. 2011; Liquete et al. 2013]. For examples, (1) they have high primary productivity and provide food materials (seaweed is consumed as food in Japan), (2) uptake nutrient and pollution in coastal zones, (3) accumulate and preserve carbon dioxide (CO₂), (4) provide suitable habitat and nursery grounds for fisheries species, and (5) provides unique and aesthetic seascapes and education places.
Macrophytes beds, however, has been markedly declining in Japan. Based on the statistics of Fisheries Agency of Japan, the area of macrophytes beds has been decreasing in recent twenty years, and now is estimated to be about 100,000 hectares, which is about a half of the area in 1990s (Figure 1). Such a decreasing trend of seaweed beds lead to loss of their diverse functions, possibly causing decline of coastal fisheries productions. Candidate causes of the decreases has been studied and discussed and grazing by herbivores is now considered to be one of main causes for it.

As terrestrial plants, seaweed flourish and wither according to the season and its biomass fluctuates through a year. However, when biomass of seaweed beds gets once decreased below a threshold, their vegetation structure is disappeared and maintained as barrens and does not recover again, which called ‘Isoyake’ [Fujita, 2002]. Isoyake is not local phenomenon and spreads over Japanese coastal waters.

Photo 2 shows a barren ground created by grazing of sea urchins. Sea urchins inhabit in high density (black dots in the photo) on the rocky shore and eat plumule of seaweed, preventing seaweed beds forming. Sea urchin is important seafood in Japan and collected by fisherman. In Isoyake state, however, an edible part (gonad) of sea urchin gets decreased and is not in good quality as food, resulting in fisherman not catching them and Isoyake being continued.

Photo 3 indicates an Isoyake area created by herbivore fishes. The whole leaf part of Ecklonia sp. was grazed by herbivore fishes, and only the stem was remaining. If the growing part at the tip of the stem is completely consumed by herbivore fishes, Ecklonia sp. will be withered.
Photo 4 shows the main herbivores that lead to Isoyake in Japan. In the northern Japan, sea urchins including *Strongylocentrotus nudus* and/or *S. intermedius* have serious damage to seaweed beds [Fujita, 2010]. In southern Japan, sea urchin *Diadema setosum* and herbivore fishes including *Siganus fuscescens*, *Calotomus japonicus*, and *Kyphosus bigibbus* mainly cause Isoyake [Fujita, 2010]. These herbivore fishes are originally from a sub-tropical region and trend of global warming may be related to increasing frequency of Isoyake caused by these fishes along coastal waters of Japan.

2 GUIDELINE FOR RECOVERY FROM ISOYAKE IN JAPAN

Figure 2 illustrates the situation of Isoyake in Japan. When grazing on seaweeds by herbivores is greater than growth of seaweeds, the balance will incline clockwise leading to Isoyake. The clockwise moving of the balance may be strengthened by other environmental changes in backgrounds such as global warming, typhoon attack, and coastal pollution. In the unbalanced situations, seaweed beds will get disappeared and

Photo 3: Barren ground by herbivore fishes

Photo 4: Typical herbivores in Japan

*Strongylocentrotus nudus* Northern sea urchin

*Strongylocentrotus intermedius* Short-spined sea urchin

*Diadema setosum* Black long spine urchin

*Siganus fuscescens* Rabbitfish

*Calotomus japonicus* White-spotted parrotfish

*Kyphosus bigibbus* Waigeu drummer
the consequent barren state will enlarge and maintain for a long time. To mitigate global warming as a background factor of Isoyake, countermeasures such as a regulation of CO$_2$ emission is undertaken on a global scale. Added to this, there are some improvement methods implemented at each fishing ground to increase the production of seaweed (downward arrow on the left) and decrease the grazing by herbivores (upward arrow on the right), although their effects are limited locally (e.g. 100 m × 100 m). A recovery guideline from Isoyake published in 2007 and revised in 2015 by Fisheries Agency focuses on efforts by local fishermen and shows the effective and efficient methods for recovering seaweed beds based on this idea.

![Figure 2: Concept of Isoyake recovery countermeasures](image)

The main users of this guideline are fishermen who should be at the core of the restoration. The main focus of the guideline is the control of intensive grazing by sea urchins and herbivorous fishes which are the main factors of Isoyake.

The major topics are as follows:

(i) Adaptive management to lead successful reforestation through adaptive learning and feedback (Figure 3).
(ii) Flow chart for selecting techniques through simplified 6 categories with minimised trial and error (Figure 4).
(iii) Organised cooperation to support fishermen by volunteers, citizens, enterprises, specialists and local governments.
(iv) Useful viewpoints for detecting decrease of seaweeds and finding critical factors in recovering seaweed beds.
(v) Explanation of each technique systematised as a tree.
(vi) Utilisation of herbivores to promote removing them and so on.

This recovery guideline from Isoyake can be downloaded from the Fisheries Agency website (http://www.jfa.maff.go.jp/j/gyoko_gyozyo/g_hourei/index.html#isoyake; in Japanese).
Figure 3: Adaptive management of Isoyake recovery countermeasures

Figure 4: Flow chart of Isoyake recovery countermeasures
3 CASE STUDIES ON RECOVERY COUNTERMEASURES FROM ISOYAKE

Although Isoyake recovery measures is described above as to (1) increase the production of seaweed and (2) decrease the grazing amount by herbivores in Figure 2, the order to take (1) and (2) is important. If (1) is carried out before (2), seaweed is grazed by herbivores immediately and recovery of seaweed beds cannot be expected because density of herbivores is still high. It is necessary to take measures of (2) firstly, and then take those of (1). To take (1) and (2), there are structural and non-structural measures for recovery from Isoyake.

3.1 Structural Measures

Photo 5 shows structural measures for the control of grazing of herbivores. (a) and (b) show structural measures for the control of grazing by sea urchin, and (c) and (d) show those for that of grazing by herbivorous fishes.

a) Even in places where sea urchins distribute in high density and seaweed beds are almost disappeared, installation of concrete blocks provides an uninvaded habitat by sea urchin and seaweeds can inhabit partially at the top of them. This is because sea urchins cannot invade or stay at the top of the block due to strong wave velocity there (more than about 40 cm/s).

b) Sea urchins generally do not inhabit on bared sand. When installing concrete blocks or stones on the sand surface with constant distance between them, density of sea urchin is kept low around there and seaweed beds can be formed on them.

c) Protecting fences are installed on the sea bottom and mature seaweeds are released inside to avoid grazing and browsing of herbivorous fishes. Although seaweed beds can flourish inside, it is rate that they extend out from the protected area of the fence. It needs to add another approach to reduce the density of herbivore fishes outside the fence for extending the seaweed beds.

d) Multiple thorns are set on the concrete blocks to prevent browsing on seaweeds by fishes. While a seaweed bed was formed at some location, field tests are still conducted in other locations to confirm the effectiveness of this method.

![Photo 5: Examples of structural measures](image-url)
3.2 Non-Structural Measures

Photo 6 shows non-structural measures for the control of grazing of herbivores. (a) and (b) show non-structural measures for the control of grazing by sea urchin, and photos (c) and (d) show the measures for that by herbivorous fishes.

a) This photo shows the underwater work of the sea urchin removal by the fisherman. Sea urchins are picked up from the seabed and put in the net bag. Because density of sea urchins exceeds 10 individuals/m² in isoyake area, it is necessary to remove more than 100,000 individuals for eradicating them within one hectare of the area. As sea urchin removal requires a lot of time and labor, fishermen need to work systematically.

b) A fisherman installs the fence on the sea bottom to prevent the intrusion of sea urchins, so that the restored seaweed beds cannot be grazed again. Metallic fence or gill net is used to make this protection area. After seaweed beds recover inside the fence, fishermen move the fences outwards to expand the range of seaweed beds.

c) and d) Fishermen are removing white-spotted parrotfish (Calotomus japonicus) and brown chub (Kyphosus bigibbus) with a gill net. They have to do it efficiently by knowing the locations and times at which the fishes gather in high density. Although it is essential to obtain the physiological/ecological information of these fishes, such information and data are still limited. We are, therefore, conducting basic studies for their ecology as well as applied studies to confirm the effects of countermeasures in cooperation with many researchers.
3.3 Seedling Spore and Embryo of Seaweed

Photo 7 shows how to seed spore and embryo of seaweed:

a) mature seaweeds are placed inside the net bags (closed spore bag) to avoid grazing and set on the sea bottom with a weight.
b) roots and stems of seaweed are placed into the net bag (opened spore bag), and the seaweeds are placed on the sea bottom with a weight.
c) the net is spread horizontally in the middle layer of the sea, and the stem of seaweed is inserted to this net using SCUBA diving. Setting closed spore bag (a) has been carried out so far at many locations, but it had a problem of seaweed withering in a few days because of little seawater exchange in the net bag.

Therefore, (b) and (c) were often used and these methods can supply spore and embryo of seaweeds continuously to the sea area as long as possible by hand. Especially, (b) is often adopted because fisherman can set spore bag on sea bottoms by throwing them from a boat and thus diving is not necessary.

3.4 Effective Use of Herbivores

Utilisation of herbivore animals caught by fishermen is very important for the effective and sustainable management of seaweed beds. The left side of Photo 8 is an example of simple pen-culture in a fishing port for sea urchins removed from urchin barrens. This example has been carried out at Hokkaido. At the beginning of the culture, sea urchins are fed with meat of fish caught in this region, and then cultivated kelps are given to make them tasty. Sea urchins reared in this method mature faster than wild individuals; therefore, their gonad can be sold at a good price in early season.
In Japan, consumption of herbivorous fishes as seafood is limited to local areas. The right side of Photo 7 shows a tasting party for checking tastes of a rabbit fish *Siganus fuscescens*. In general, a rabbit fish is not favorite seafood for many Japanese because of smell of the fish meat and a toxic spine in their dorsal fins. However, the dishes of rabbit fish had good reputation when cooked well without damaging viscera in the party. To popularise the taste of herbivore fishes aiming its commercialisation, holding a tasting party may be a good way and its frequency should be increased.

### 3.5 Evidence of Seaweed Bed Restoration by Isoyake Countermeasures

Photo 9 shows a recovery of seaweed beds by isoyake countermeasures mentioned above. The top side of Photo 9 shows the condition before the countermeasure and the bottom side shows that after it. Each example succeeds in recovering seaweed beds of a few hectares. Currently, the coast of Japan has a severe environment conditions for the growth of seaweeds including a rise in seawater temperature and influence of herbivores feeding, but the examples around Japan show that seaweed beds can recover if people firmly take the countermeasures to decrease herbivores and increase seaweed productions. Recovery of seaweed beds is expected to create habitats for diverse animals and to lead stock recovery of coastal fisheries species such as abalones and Japanese lobsters.

![Photo 9: Evidence of seaweed bed restoration by isoyake countermeasures](image)

**Shiriya, Aomori Pref.**

**Kutu, Koch Pref.**

**Oseto, Nagasaki Pref.**

### 4 CONCLUSION

This report introduced the recovery of seaweed beds in Japan based on the guideline for Isoyake recovery (Fisheries Agency in Japan). Countermeasures based on this guideline are currently implemented nationwide by fishermen in cooperation with a wide range of stakeholders in the project of the Fisheries Agency. In fiscal 2017, conservation and restoration measures for seaweed beds were implemented in 299 organizations. The activities include removal of sea urchins (155), seaweed seedlings (102), and bedrock cleaning (85) in order. In this project, support staffs appointed by the Fisheries Agency provide training sessions and technical guidance to fishermen every year. Their activities and progresses are presented at a meeting of an isoyake recovery council held at Tokyo at the end of the fiscal year, and case examples of the fisherman’s efforts are introduced. Efforts of this project are online in the following HP (National Federation of Fisheries Cooperative).
REFERENCES


SUMMARY

Reduction of seaweed beds called ‘Isoyake’ has become a serious problem in most of coastal prefectures in Japan. Though many researches and investigations have been carried out for isoyake recovery, practical and effective methods have yet to be established. To overcome this situation, Fisheries Agency of Japan published an ‘Isoyake Recovery Guideline’ in 2007 and revised it in 2015. Main users of this guideline are fishermen who are expected to play a key role in restoration activities. The main theme is the control of intensive grazing by sea urchins and herbivorous fish. Major topics are as follows: (i) adaptive management for successful reforestation through continuous learning and feedback control, (ii) flow chart consisted of simplified six categories for selecting appropriate recovery techniques, (iii) organised cooperation of volunteers, citizens, enterprises, specialists, and local governments to support fishermen, (iv) useful viewpoints for detecting causes of seaweed decrease and determining critical factors in recovering seaweed beds, (v) explanation of each recovery technique, and (vi) utilisation of herbivores for food. The non-structural/structural countermeasures based on this guideline have been implemented nationwide in Japan. Though negative conditions for recovery of seaweed beds are increasing (e.g. the rise in seawater temperature and the increasing intensity of typhoons), there are some successful examples in which a few hectares of seaweed beds have recovered thanks to the efforts of fishermen and other stakeholders. In fiscal year 2017 (from April 2017 to March 2018), conservation and restoration activities for seaweed beds were carried out by 299 groups. The activities include removal of sea urchins (155), seaweed seedlings (102), and bedrock cleaning (85). In this project, Fisheries Agency has been assigning support staff to local regions to provide training sessions and technical guidance for seaweed recovery every year. Their activities and progress are reported a meeting of an ‘Isoyake recovery council’ held at Tokyo at the end of the fiscal year where case examples of the fishermen’s efforts are introduced.

RESUME

La réduction des bancs d’algues « Isoyake » est devenu un sérieux problème dans la plupart des préfectures côtières au Japon. Bien que de nombreuses recherches et enquêtes ont été menées pour les sauvegarder, des méthodes pratiques et efficaces doivent encore être mises en place.

Les principaux utilisateurs de ce guide sont les pêcheurs qui devraient jouer un rôle clé dans les activités de restauration. Le thème principal est le contrôle du pâturage intensif par les oursins et les poissons herbivores.

Les principales actions sont les suivantes :

(i) une gestion adaptative pour la recolonisation réussie, grâce à un suivi continu et l'analyse du retour d’expérience; (ii) un arbre de choix simplifié qui permet d’identifier la plus adaptée des six techniques de sauvegarde; (iii) une coopération organisée entre bénévoles, citoyens, entreprises, spécialistes et gouvernements locaux pour soutenir les pêcheurs; (iv) identifier les points-clés des causes de la diminution des algues et les facteurs déterminants pour la restauration des bancs d’algues; (v) La description de chaque technique de restauration et (vi) la consommation des espèces herbivores.

Les mesures correctives non-structurales et structurelles liés à cette directive ont été mises en œuvre à l'échelle nationale au Japon.

Bien que les conditions pour la restauration des lits d'algues soient défavorables (par exemple l'augmentation de l'eau de mer et l'augmentation de l'intensité des typhons), il y a quelques exemples réussis dans lesquels quelques hectares de bancs d’algues ont pu être restaurés grâce aux efforts des pêcheurs et autres partenaires. Durant l'exercice 2017 (d'avril 2017 à mars 2018), 299 actions de conservation ou de restauration des bancs d’algues ont été menées. Les actions comprennent le prélèvement des oursins (155 actions), la plantation d’algues (102 actions), et le nettoyage des fonds marins (85 actions).

Dans ce projet, chaque année l'agence des pêches a affecté du personnel pour soutenir les administrations locales sous forme de formation et de conseils techniques liés à la conservation des algues. Chaque année, à la fin de l'exercice, Les actions menées et les avancées obtenues sont présentées à Tokyo lors d'une séance « conseil de restauration de l’algue Isoyake », avec présentation d'études de cas liés aux efforts consentis par les pêcheurs.

**ZUSAMMENFASSUNG**


Die Hauptpunkte sind wie folgt:


Die auf dieser Richtlinie basierenden nicht-strukturellen/strukturellen Gegenmaßnahmen wurden landesweit in Japan eingeführt. Obwohl die negativen Bedingungen für die Erholung der Tangwälder steigen (z. B. der Anstieg der Meereswassertemperatur und die steigende Stärke von Taifunen), gibt es einige erfolgreiche Beispiele, bei denen sich einige wenige Hektar Tangwälder erholt haben, dank der Bemühungen der Fischer und anderer Interessensvertreter. Im Geschäftsjahr 2017 (von April 2017 bis März 2018) wurden Erhaltungs- und Wiederherstellungsaktivitäten für Tangwälder von 299 Gruppen...

RESUMEN

La reducción de las praderas de algas marinas denominadas 'Isoyake' se ha convertido en un serio problema en la mayoría de las prefecturas costeras de Japón. A pesar de que se han llevado a cabo numerosos proyectos e investigaciones para la recuperación de las 'isoyake', aún no se ha conseguido encontrar un método que resulte suficientemente efectivo. Para solventar esta situación, la Agencia de Pesca de Japón publicó en 2007 una 'Guía para la recuperación de isoyake', revisada posteriormente en 2015. La mayoría de usuarios de estas recomendaciones eran pescadores que se esperaba jugasen un papel determinante en la restauración de estas zonas. El aspecto fundamental resulta ser el control del pasto intensivo que realizan los erizos de mar y los peces herbívoros.

Los elementos más relevantes resultan ser: (i) gestión adaptativa para el éxito de la reforestación, a través del aprendizaje continuo y realimentación de resultados, (ii) diagrama de flujo que recoge seis categorías simplificadas para seleccionar la técnica apropiada de recuperación, (iii) organización de la cooperación entre voluntarios, ciudadanos, empresas, especialistas y gobiernos locales para dar apoyo a los pescadores, (iv) puntos de vista útiles para diagnosticar las causas de la pérdida de praderas y determinar los factores críticos que inciden en su recuperación, (v) explicación de las técnicas de recuperación, y (vi) utilización de especies herbívoras. Las medidas estructurales y no estructurales recogidas en esta guía han sido puestas en práctica a lo largo de todo el país. Aunque las condiciones de recuperación de las praderas marinas están empeorando (por ejemplo, por el efecto del incremento de la temperatura del agua o la mayor frecuencia en la aparición de tifones), existen ejemplos de éxito en los que se ha conseguido recuperar algunas hectáreas de praderas gracias al esfuerzo de los pescadores y otras partes interesadas. Durante el año fiscal de 2017 (abril 2017 a marzo 2018), un total de 299 grupos desarrollaron proyectos de conservación y recuperación de praderas marinas. Las actividades llevadas a cabo incluyeron la retirada de erizos de mar (155), plantación de semillas en las praderas (102) y limpieza de fondos (85). En este proyecto, la Agencia de Pesca ha prestado su apoyo a las instituciones locales en la organización de jornadas anuales explicativas sobre técnicas de recuperación de praderas marinas. Las actividades y los avances llevados a cabo son recogidos por el 'Consejo de Recuperación de Isoyake' con sede en Tokio, que cada año muestra los avances y ejemplos desarrollados a lo largo del año fiscal por las comunidades de pescadores.